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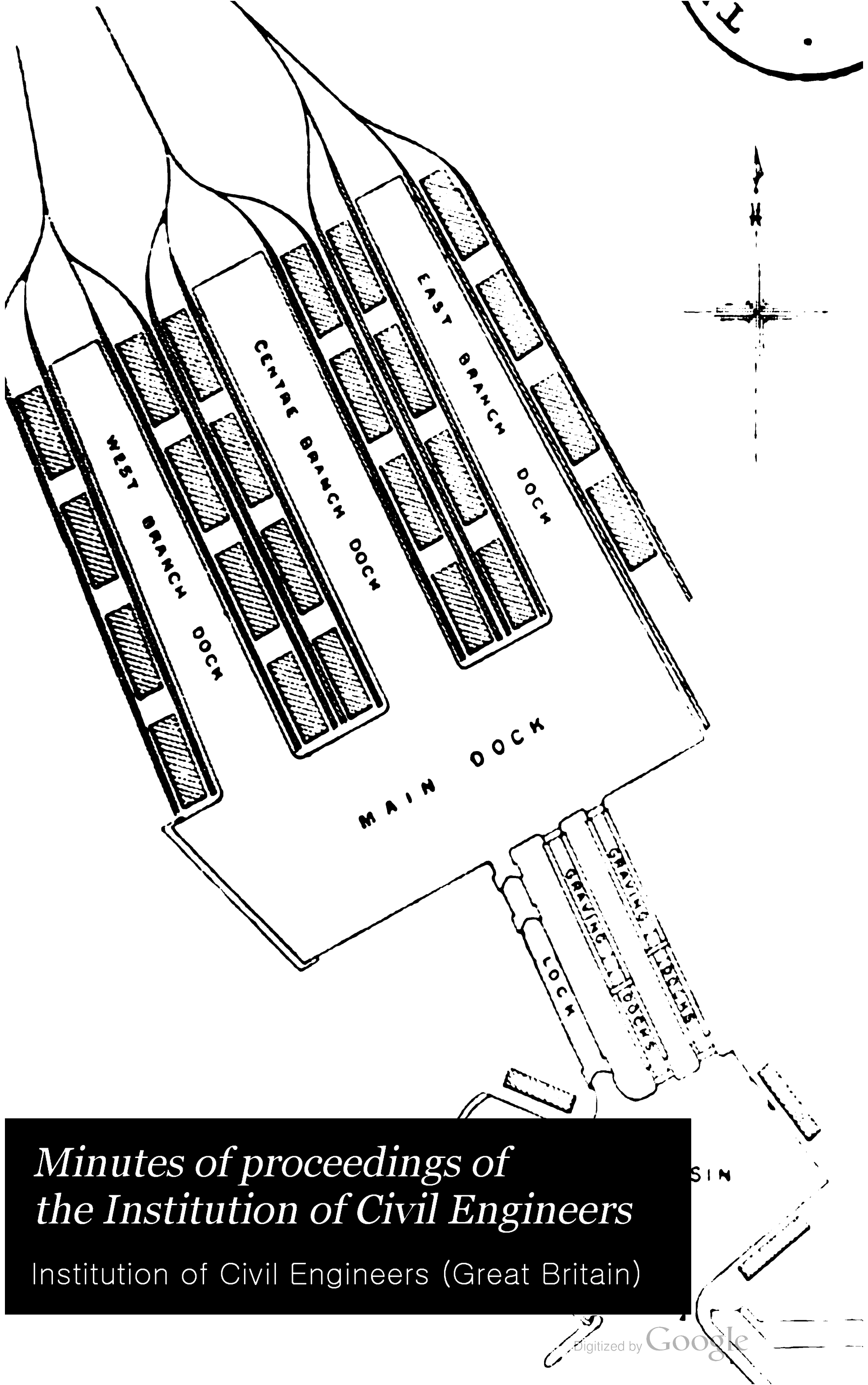

Minutes of proceedings of the Institution of Civil Engineers

Institution of Civil Engineers (Great Britain)

Engineering
London Soc. civil & [illegible]

MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. C.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

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THE INSTITUTION OF CIVIL ENGINEERS.

SESSION 1889-90.—PART II.

Sect. I.—MINUTES OF PROCEEDINGS.

14 January, 1890.

Sir JOHN COODE, K.C.M.G., President,
in the Chair.

The following Associate Members have been transferred to the class of

Members.

Charles Malcolm Johnson, R.N.
Claude William Kinder.
George Henry Peace.

The following Candidates have been admitted as

Students.

Jesse Liddel Altham.
Donald Allan Andrus.
Hugh Garratt Barham.
Philip James Bevan.
Frederick Fleetwood Bion.
Cuthbert Miller Burnett.
Hugo von Reitzenstein Cunliffe-Owen.
Hawtrey Marks Drummond.
Edgar Hunter Fairgrieve, B.Sc.
Leonard George Hall.
Hubert Decimus Henry.
Edward Charles Hodge.
Rowland John Jefferis.
Kenneth Smale Laurie.
James Christian Paulson.
Francis Charles Raphael.
Hugh Frederic Arthur Rotton.
Joseph Shepherd.
Charles Vincent Nixon Shortland.
John Barton Stephens.
Ernest Wright.

The following Candidates were balloted for and duly elected as

Members.

Alexander Atkinson, L.C.E.
Frederick Wells.

Associate Members.

William Henry Brace.
John Alexander Brodie, Wh. Sc.
John Blair Buchanan, Stud. Inst. C.E.
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Arthur Pitt Chambers Cary, Stud. Inst. C.E.
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William Ben Edwards, B.E., Stud. Inst. C.E.
David Fulton.
Norman Walter John Gibson, Stud. Inst. C.E.
Herbert James Gifford, Stud. Inst. C.E.
Arthur Harnett, Stud. Inst. C.E.

Associate Members—continued.

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Charles Murray, Stud. Inst. C.E.
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John Hodgson Stuart.
Allan Archibald Campbell Swinton.
William Henry Thorpe.
Arthur Williamson, Stud. Inst. C.E.
George Wylie, F.C.H.

Associate.

Major Leandro Cubillo.

(*Paper No. 2433.*)

"Recent Dock Extensions at Liverpool, with a General Description of the Mersey Dock Estate, the Port of Liverpool, and the River Mersey."

By George Fosbery Lyster, M. Inst. C.E.

The special characteristics of the River Mersey, the important position which Liverpool occupies among the leading trading centres of the world, and the rapid development of its commerce are, each and all, so interesting to engineers, that in submitting a Paper descriptive of the most recent dock extensions carried out in the port, the Author has been induced to touch upon each of these points, as a fitting preamble to the more formal and precise description of the special works which form the leading features of the Paper.

Few, if any, localities, in this country at all events, are so favourably situated for the construction of a comprehensive system of docks as that of Liverpool, not only by reason of its geographical position on the seaboard of the country, with its unrivalled water frontage, but also on account of its proximity to the great manufacturing districts, as well as to the coal and mineral fields of the North of England and Wales, with which it is linked by railways and canals, which are such important factors in the development and maintenance of successful trading.

Such a combination of advantages could not fail, if properly dealt with, to make Liverpool a great port, and this is clearly demonstrated by the continuous advance in its trade and revenue since it was a mere fishing village, until now, when it stands in the very foremost rank of the seaports of the world. In 1800, the vessels trading to Liverpool during the year numbered four thousand seven hundred and forty-six, of 450,060 tons register, and brought in a revenue from dues of £23,380 to the Municipality, to whom the docks then belonged; whereas in the financial year ending the 30th of June, 1889, the total number of ships entering was twenty-two thousand six hundred and sixty-two, of 9,292,000 register tons, producing a revenue from dues of £990,550 to the Dock Board.

Without entering minutely into a description of the Mersey and its characteristic features, it may be stated that the entire length of the river bearing that name is 56 miles. It rises in the Derbyshire hills on the borders of Yorkshire and Cheshire, and the general direction of its flow for the first 37 miles, that is until it reaches the town of Runcorn, is westwardly. Down to this point it is an ordinary river with parallel banks, having a tortuous course through an agricultural country chiefly of the Red Sandstone formation. At Runcorn Gap it intersects the Red Sandstone "bluffs." Here it takes a sudden bend, nearly at a right-angle to its upland course, and expands into a shallow estuary from 2 to 3 miles in width, following a north-westerly direction to the sea, which it enters at New Brighton. For the last 6 miles of its course, along which the city of Liverpool is situated on its right bank, and the town of Birkenhead on its left, with their several systems of docks, the river becomes contracted, and at its narrowest point, opposite the centre of Liverpool, its width is only a little over 3,000 feet. Its shores, on each side, rise gradually inland, and afford excellent shelter from the prevailing winds. It will thus be seen that, from Runcorn to the sea, the Mersey is of a shape which has been aptly described as that of a "bottle," of which the wide expanse between Runcorn and Liverpool forms the "body," and the 6 miles of "narrows," opposite Liverpool, the "neck."

Between its source and the town of Runcorn, the Mersey receives several tributaries, the principal being the Tame, Irwell, and Bollin, on the second of which, at about 8 miles from its junction with the Mersey, is situate the city of Manchester.

The total area of country drained by the river to Woolston weir, a point about 5 miles above Warrington, is about 750 square miles.

Below Warrington, no considerable stream joins the Mersey until the town of Runcorn is passed, a mile below which the Weaver, a very important tributary, discharges its water into the estuary from the left bank, its junction and general direction being nearly at a right-angle thereto. This river has its source in the southern portion of Cheshire, and, with its tributaries, drains a great part of the centre of the county, the area of its catchment basin being about 550 square miles.

These rivers, with other minor affluents of the Mersey, bring up the total area of its drainage basin to about 1,724 square miles. The rainfall within that area varies in different localities from 25 to 53 inches per annum. The upland water discharged into the estuary is computed at from 2,000,000 to 3,000,000 cubic yards in twelve hours.

The highest point on the Mersey reached by the tide is Woolston weir, and to this point only extreme spring-tides flow. Neap-tides do not reach a higher point than "Fiddler's Ferry," about 5 miles below Warrington. On the River Weaver ordinary tides reach Sutton weir, near Frodsham, about 2 miles from the junction with the Mersey. The tidal water passing in and out from the sea, through the channel abreast of New Brighton, has been estimated at 710,000,000 cubic yards on a high spring, and 281,000,000 cubic yards on a low neap-tide.

Compared with these figures, the amount of upland water appears insignificant, yet combined with the tidal flow and ebb, it plays a most important part in maintaining the regime of the river, and counteracting the process of silting which is continuously going on throughout the estuary.

The total tidal area of this estuary, within the mouth of the river at New Brighton, is 22,500 acres, the greater portion of which, between Runcorn and the narrows at Liverpool and Birkenhead, is filled with a deposit of sand, 17,300 acres being above the level of low-water of spring-tides. Through this vast extent of sand the upland water, when the tide is sufficiently low to permit it, ploughs its way and forms a channel for itself in its course to the sea. The direction of this channel is never constant for any length of time, and by its incessant wanderings through the wide estuary permanent accretion is prevented.

On this peculiar feature no doubt the maintenance of the Mersey as a great tidal receptacle mainly depends; and were any stoppage or interference with the roving tendency of the low-water channel permitted, permanent accumulation must take place, and the growth of solid land, to the exclusion of a corresponding bulk of tidal water, would be the inevitable result.

The importance of this fact cannot be too strongly urged, as it is a universally accepted opinion, by competent authorities, that any extensive exclusion of tidal water from the estuary must injuriously affect the sea-channels, and finally destroy the port of Liverpool.

The deep-water channel of the Mersey commences below the upper estuary, with the contraction of the river at Dingle Point, where it is 7,200 feet in width. It extends in a northerly direction in a fairly straight line, to the mouth of the river at New Brighton, where it is about 5,600 feet wide, though at an intermediate point opposite the centre of Liverpool, as before mentioned, the width is only about 3,000 feet.

For the whole range of this portion of the Mersey, there is plenty of water for vessels, the depth at low-water of spring-tides being about 40 feet at the Dingle, 50 feet at Seacombe, and 70 feet abreast of New Brighton. These depths are always fully maintained, as the tides run with great rapidity through the "narrows,' the velocity at springs being 6 to 7 knots an hour.

The immediate foreshores of this "deep" have a sandy fringe, which towards its southern extremity, on the Liverpool side, assumes a projection of considerable and inconvenient proportions, known as the Pluckington Bank, the existence of which is mainly due to the deflection of the ebb currents to the Cheshire shore, by the rocks at Dingle Point.

Along the whole of this "reach" the anchorage is good, so that vessels of the largest size lie moored with safety in any weather.

Upwards from the southern extremity of the Dock Estate extend two well-defined channels, one on the Lancashire side being navigable for vessels of light draught as far as Garston, the other on the Cheshire side as far as Eastham. The latter, known as the Sloyne, is for the greater portion of its length wide and deep, affording excellent anchorage for all classes of vessels, including the old men-of-war now used as school and reformatory ships. The Cunard steamships also have long moored in this position, while fleets of sailing coasters, waiting for suitable weather, make it their anchoring ground; as many as one hundred and fifty vessels may frequently be seen lying there at the same time.

At the upper end of the channel, near Eastham, three floating powder-magazines are moored clear of other craft.

From the mouth of the river seawards, as far as the Crosby Lightship, a distance of 6 miles, the direction of the main channel, known as the Crosby Channel, takes a slightly divergent course about two points to the westward of its general direction passing Liverpool; its depth and width being fairly maintained, though in places the depth is somewhat reduced. This reduction in depth is doubtless due to the Rock Channel, depriving the main channel of a portion of scouring water by the rapid deflection of a large volume of the ebb-tide stream to the westward, immediately on its passing the Rock Point.

Fortunately no serious detriment to the depth of the main channel is likely to occur from this cause, as the bottom of the Rock Channel at its junction with the Crosby Channel is solid rock, and awash at low-water of spring-tides, thus forming a sill to the passage of the tidal stream, so that no further deepening can occur here, and this combined with the fact that the Rock Channel has for some years given evidence of deterioration in width, depth and directness, lead to the conclusion that in future it will be even less available for vessels than at present, when it is only used for craft of the smaller coasting class.

At the Crosby Light-ship the general direction of the main channel again slightly alters to the westward, and so continues to the bar, its navigating width, as defined by the buoys, varying from ½ to ¾ mile, and its depth from 25 to 50 feet at low-water of spring-tides. At its outer end, where it bears the name of the Queen's Channel, it terminates in the bar, the form of which is on plan somewhat that of an irregular horse-shoe, with its convex side facing the sea.

The navigating depth over the bar at lowest low-water of spring-tides is 10 feet, and the range of the tide is 30 feet at springs, while neap-tides have a range of 10 feet, with a high-water 20 feet above low-water springs. Thus the depth of water on the bar at high-water of spring-tides is 40 feet, and at high-water of neap-tides 30 feet.

The total distance from the mouth of the river at New Brighton to the crest of the bar, measured along the sailing course, is 11 miles.

On each side of the main sailing channel are vast areas of sand partially intersected by blind channels and runs of water, which apparently are without any tendency to become more prominent. These banks, more or less, fill up the embayment formed by the Lancashire and Cheshire coasts, and, but for the action of the river and tidal water, would become solid from shore to shore, with a sea-face in the form of an ordinary beach. The aggregate area of these outer banks which dries at low-water is 23,000 acres.

Although these, as well as other minor channels, pass through frequent phases of change, the unassisted efforts of nature have hitherto maintained them so fairly stable, that the conditions of navigation remain practically uniform.

The bar is constantly but gradually moving in a seaward direction, maintaining, however, its general form and characteristics.[1]

The general range of tide must be considered as affording a comparatively convenient approach for even the largest vessels; nevertheless, as the tendency is towards a further increase in the size of ships, and when time forms such an important element of successful trading, a deeper channel would evidently be desirable. The attainment of such an end is, however, surrounded with physical and financial difficulties of no ordinary character, and though the question is kept prominently in view, no definite steps of magnitude have yet been taken towards its solution.

The main channel from the bar inwards is buoyed and lighted on the most approved principle throughout its whole course, so that the highway leading to the port partakes of the character of a well-defined street, easily and safely used by night as well as by day. The Rock and Formby channels are also fully lighted and buoyed.

The Author trusts that this very general outline of the Mersey and its characteristic features may be considered an appropriate preface to the more particular description of the dock estate, and the recent work undertaken by the Dock Board.

So far back as 1550 Liverpool occupied a somewhat important position in whatever maritime trade existed on the western seaboard of the country, and the port was then regarded as one of the best natural harbours along this coast.

From such local records as exist, meagre as they are, it is evident that considerable energy and foresight were displayed in making improvements from time to time to secure the safety and convenience of the vessels which traded to the port. These, at the outset, were few in number and small in size. It is recorded that fifteen vessels with a gross burden of 268 tons, represented the extent of the shipping trading from the Mersey in 1565.

The site of the original port was a shallow creek, which ran inland from the right bank of the river in a north-easterly direction, commencing at a point about midway of the "deep," where the existing Custom-House stands, and extending along the depression now occupied by Paradise Street. Its length was about 1 mile, and judging from its position, it must have been well sheltered from the action of the prevailing winds.

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[1] Since this Paper was written it has been decided by the Mersey Docks and Harbour Board to experiment on the dredging of the bar, for which purpose the expenditure of a certain sum of money on the fitting out and working of sand-pump dredgers has been authorized. The Author is now (January, 1890) making preparations for this work.

From the fact of there being no record of wharves or quays, vessels must have loaded and discharged their cargoes either by means of boats in the river, or by grounding on the banks of the creek, and making use of carts at low-water, as is now so frequently done in the small ports and inlets along the seaboard of the country.

Owing to the rapid development of manufactures in the north-western counties, it became evident, in the early part of last century, that the time had arrived when steps should be taken to provide improved accommodation for the larger class of vessels which made Liverpool their port of arrival and departure. There were not wanting men of energy and enterprise to face the problem, and it is recorded that these pioneers of progress had the honour of devising and constructing the first wet-dock built in England, thus setting an example to other important ports which have come into existence, and have helped to bring the trade of the kingdom to its present greatness.

In 1708, in the reign of Queen Anne, parliamentary authority was obtained for the construction of a wet-dock at the mouth of the old pool referred to.

It was 4 acres in area, and was designed and constructed by Mr. Thomas Steers, to afford accommodation for one hundred vessels, and so arranged as to have not less than 10 feet of water within it at low neap-tides, with a sufficiency at springs to accommodate the smaller class of war-ships.

Since then the trade and port have steadily progressed, but under very altered conditions. The Old Dock has long since passed away, and its site is now covered by public buildings. No direct trace of the Old Pool is noticeable, though its previous existence may be inferred from the depression of the street surfaces along the line of its former course, and from the character of the excavations which have been frequently made in its vicinity.

It was long thought that the filling up of this dock and the utilization of its area in the manner described was a mistake on the part of the authorities; but such an opinion cannot be sustained with any show of soundness, as the severance of the city, by perpetuating a dock through its midst, must have ultimately proved an intolerable nuisance, and have entirely prevented the convenient working of the street traffic.

The sites for the development and extension of the existing dock system on the Liverpool side, have been chosen along the margin of the river, abutting for the most part upon the deep water of the channel. Here, for a length of over 6 miles, and for a width varying from 700 to 2,200 feet, the foreshore on the Liverpool side, for a considerable extent between high and low-water, has been enclosed from tidal influence, by the construction of a continuous sea-wall, except where entrances were required into the range of docks behind it.

The whole of the docks of the Mersey have been constructed under parliamentary powers, obtained from time to time as the requirements of trade indicated the necessities of extension.

To indicate this state of constant progression, the several lands and foreshores obtained under the different Acts of Parliament, have been outlined (Plate 1), with the dates of each acquisition set forth thereon.

The earlier docks were commenced abreast of the Old Dock, and extended both towards the north and south, including the Salthouse, George's, and Prince's group; all remain to this day, and some of them without alteration, thus testifying to the foresight with which they were designed and carried out by Mr. John Foster and his son, the Surveyors to the Corporation, by whom the affairs of the docks were then administered.

In 1824, Mr. Jesse Hartley became the Surveyor and Engineer to the estate, and designed and carried out the docks with their warehouses and surroundings between the Prince's and the Canada in a northerly direction, and the Canning, Wapping, Coburg, and Brunswick, with other minor groups towards the south; in fact, to his ability and practical knowledge, during the thirty-six years he occupied the position of engineer to the estate, Liverpool undoubtedly owes much of its commercial greatness.

In 1861 the Author became Engineer to the Dock Estate, and subsequently carried out works increasing the dock accommodation at Liverpool, including the rearrangement of the docks and basins in the vicinity of the Waterloo Dock, and the construction of a large group of grain warehouses, the Herculaneum Half-Tide Dock and Graving-Docks, the Huskisson Branch Dock No. 2, and enlargement of the Canada Half-Tide Dock, now named Brocklebank Dock.

Extensive alterations were also made to meet the pressing requirements of the ferry traffic, which had assumed very large proportions, and demanded improved approaches between the City of Liverpool and the stages. The George's Basin and Seacombe Ferry Basin were filled up, and the George's and Prince's stages united by a new stage, to which a floating roadway on the site of the George's Basin gives easy access.

While rapid strides had been made in the development of the dock system on the Lancashire side of the Mersey, extensive docks had also been constructed on the Cheshire side. The site of these was the Wallasey Pool, a tidal creek, similar in general characteristics to the Old Pool at Liverpool, which ran inland for a distance of about 2 miles from a point abreast of the centre of Liverpool. This creek was acquired under an Act of Parliament by the Birkenhead Docks Committee, an incorporated body formed to undertake the construction of a great dock scheme, to vie with Liverpool in magnitude, and intended to compete for the trade of which it had until then the monopoly. The original design for the works was by the late Mr. James Meadows Rendel, Past President of this Institution.[1]

When in the hands of its projectors, the characteristic feature of the Birkenhead Docks system was the dock built on the site of the Wallasey Pool, and known as the Great Float, about 120 acres in area, to be approached from the river through a deep tidal basin known as the Great Low-Water Basin.

In 1858, the Mersey Docks and Harbour Board was incorporated by Act of Parliament, to take over and manage the whole of the Liverpool and Birkenhead Docks, which, since that time, have formed one estate, having common funds, and being administered under identical conditions.

Considerable alterations in the original design of the Birkenhead Docks were made by Mr. John B. Hartley, who assisted, and subsequently succeeded his father, Mr. Jesse Hartley, as Engineer to the Mersey Dock Estate, but who, owing to broken health, was obliged to retire from the profession.

In 1861, when the Author became Engineer to the Board, the works at Birkenhead had only recently been commenced. They have since been carried out to a great extent in conformity with Mr. Hartley's designs, but with large additions in the way of warehouses, graving-docks, sheds, and other such like furnishings, to bring the estate into full practical use.

The Great Low-Water Basin, however, has undergone an important change. After two or three years' experience, it was found to be so costly and inconvenient in working, that its use in an open condition had to be abandoned, and it has since been altered into a dock of the ordinary type, named the Wallasey Dock, and is now frequented by prominent lines of steam-ships.

It will be impossible, with any degree of justice, to attempt more than this brief description of these great works. They have been the outcome of many powerful minds and varied interests,

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[1] Minutes of Proceedings Inst. C.E., vol. xxviii. p. 518; and vol. xxix. p. 3.

and present points well worthy of the careful study of those who follow this special branch of the profession.

Reverting to Liverpool, the Act of 1708, which has already been referred to, was the first of a long series of Acts of Parliament authorizing the acquisition of lands and foreshores, and providing for the construction of groups of docks on the Liverpool side.

In 1871, although the Birkenhead Docks system had been for some time completed according to the parliamentary plans, and sufficiently furnished with warehouses and shed accommodation of an elaborate and extensive description, the Dock Board was urged to consider the desirability of commencing without delay further dock extension on the Liverpool side of the river, on such a scale as would meet the pressing wants of trade, and provide for the growing requirements of shipping, which was everywhere advancing in size and tonnage. The result of this pressure, was an exhaustive inquiry into the question by a committee of the Board, with the outcome that the Author was directed "To consider and report as to the capabilities of the Mersey Dock Estate, in its then condition, to meet the probable requirements of the great and increasing commerce of the port, and as to the alterations or additions which might be requisite for that purpose, or which might appear to be called for on a comprehensive view of the general policy of the Trust."

Accordingly the Author submitted reports and plans dealing with the whole of the undeveloped lands of the Board at Liverpool, showing how they might be brought into use as dock space for steam or sailing-ships of the largest class. The plans referred to included three groups, or systems of docks, viz.:—

The northern group along the margin of the river, northward of the Canada Basin;

A central group situated inland, eastward of the Sandon Dock;

And the southern group, also on the river margin, at the then southernmost extremity of the estate.

Of these schemes the northern and southern extensions were adopted, while that inland, near the Sandon Dock, was set aside as unnecessary at that time.

In the Session of 1873, powers were sought to carry out the works, the estimate for which amounted to £4,100,000, and after lengthened discussion in committee, the Board's proposals were duly approved and sanctioned by Parliament. The proposed extensions being intended not merely to meet the wants of the port at the time of the passing of the Act, but also to provide, as far as possible, for some years ahead of that time, a clause was inserted in the Act limiting the expenditure to £500,000 per annum. The execution of the works has accordingly been spread over many years, the effect being that before any of the several new works have been opened, trade in its natural advance, has been ready to fill them.

The land at the northern extremity of the estate, on which new docks were to be constructed, consisted of foreshore abreast of the township of Bootle, covered at high spring-tides, and which, in days gone by, had been the favourite bathing resort of the inhabitants of Liverpool and its suburbs. The whole of the back country of the district is on a level nearly coincident with that of the dock quays, consequently it presented a valuable site for town extension, which has rapidly gone forward since the dock works were undertaken.

As a preliminary to dock development, the first step had been some years previously taken by the Author, in the construction of a sea-wall parallel with the low-water margin of the river, extending from the north pier of the Canada Basin to Rimrose Brook, a distance of about 6,400 feet. This wall is of an exceedingly substantial and massive character, having to withstand the impact of the waves, and to screen the works from breaking seas. During on-shore gales the waves course along its entire length, frequently attaining the height of the coping, 15 feet above high-water, and in exceptionally heavy gales, breaking over in heavy masses.

To ensure the quays and roadways against damage, the wall has been finished by a parapet 4 feet high, behind which there is a parade 20 feet wide, and 4 feet above the level of the adjoining roadway.

The wall is for the most part founded on boulder clay, and as the foreshore falls somewhat rapidly seawards, the toe is secured by whole-timber sheet-piling, waled and cut off at about the normal level of the shore. The face-work is of granite, for the most part in large blocks of irregular shape, with the best beds down, and dressed on the joints for a depth of about 6 inches from the face, the spaces between the large blocks being made up of granite rubble, treated in a similar manner. It is coped with heavy square blocks of irregular depths, interlocked by granite joggles. The backing is of sandstone.

This class of uncoursed masonry was adopted as the best suited for the granite in use on the dock estate, which is obtained from the Board's own quarries in the south of Scotland. Though the stone from that district is of excellent character, its beds are so dislocated as to render it difficult to get it in square blocks, such as are produced in the Cornish quarries.

About midway between the Canada Basin and the Seaforth

Battery is the North Wall lighthouse, in which is a dioptric light of the first order, one of the leading lights of the sea channels. This lighthouse, with the lightkeepers' cottages attached, was constructed by the Author in 1876.

The enclosure of the foreshore was completed by a return wall at Rimrose Brook. This wall is built entirely of red sandstone, and is 2,200 feet long. In a large culvert behind it, the waters of Rimrose Brook are conveyed to low-water level.

At the salient angle of the two walls the Author, at the special request of, and according to plans furnished by, Government, constructed a granite fort, which now forms the foremost defence of the river. It mounts four 38-ton guns.

The area of the foreshore included within the northern enclosure is about 300 acres. The area thus reclaimed consisted of sand overlying boulder clay, with here and there rock at varying depths not far down, but none cropping to the surface. The enclosure presented an admirable site for the construction of docks, and though at the time, and before the works were commenced, many objections were raised to its exposed position, as well as to its remoteness from the centre of business at the Exchange, the Author contended that it was the only available site on which docks of the requisite character could be constructed; that it permitted of their being laid out in the most convenient form, and so as to be easily accessible in any weather, and that it presented facilities for construction not often obtainable for this class of work. As regards the distance from the Exchange, it was considered that the telegraph and improved railway accommodation would doubtless counteract this inconvenience.

It was by no means surprising that these objections should have been urged by those who judged the matter by the antecedent working of the entrance to the Canada Dock, through its 100 feet lock. That entrance, in the original condition of the basin, was undoubtedly difficult to enter, owing to its guiding heads pointing in a northerly direction, in line with the flood currents, and to its being, in certain weather, much exposed. This is evidenced by the fact of its storm-gates having been carried away by a heavy gale on a spring-tide in 1868.

The general features of the design of the new works comprised the following:—

The enlargement and deepening of the Canada Basin, and the improvement of its entrance, so as to make it available for vessels of the largest class.

The Langton Dock, of 18 acres, serving as a half-tide dock, or vestibule for shipping, as well as for ordinary purposes of trade.

The Langton Branch Dock and Graving-Docks, projecting from the east quay of the Langton Dock. The branch dock was originally intended to serve entirely as a repairing dock, and was therefore placed convenient to the graving-docks.

The Alexandra Dock, of 44 acres, giving berthage to the largest transatlantic liners. This dock consists of a main trunk lying north and south, and three branches projecting from its east side.

The Hornby Dock, 17 acres, intended for the accommodation of the timber trade.

The enlargement of the Canada Basin was effected by the removal of the north and north-west walls; no alteration was made to the east and south walls, in which are important entrances of moderate depth leading to the older docks.

The width of the opening from the river was also increased from 250 feet to 390 feet by the removal of the north pier-head, and timber jetties were erected, splaying out riverwards from the north and south pier-heads.

The basin, and the passages between it and the Langton Dock, have been designed to ensure an easy and convenient entrance to the New North Docks, and this object has been fully attained.

At the Liverpool Docks ships generally enter and leave during the last two hours of flood-tide, so that the gates can be closed at high-water, or soon after. It follows that all ships as a rule, and large vessels almost invariably, approach the entrance heading north against the flood-tide, so as to admit of their being kept under proper control. In designing the new entrances, therefore, their angle with the river wall was made acute, and their position so arranged as to give as direct a lead as possible from the river into the dock.

Vessels can thus pass quickly through them without warping, and so allow of a large number docking on one tide, a most important point when it is considered that the basin serves, not merely as the only entrance to the great new system of docks to the northward, but as a principal entrance to the Canada, Huskisson, and Brocklebank Docks to the southward and eastward.

The ease by which the new system is approached has daily been demonstrated since the docks were opened in 1881, the dock officials in charge having frequently reported that they have scarcely ever been prevented docking and undocking the largest ships, even during the heaviest gales.

As an isolated instance of the amount of work that can be done in this basin, a report has been submitted by the Dock Master, stating that on the 13th of February, 1889, twenty-three steamships of the largest class were docked and undocked, equivalent to 34,197 tons burden, and thirty-five smaller craft and flats, during a working period of two and one-third hours.

It should here be explained that the entrances, as shown on the parliamentary plans, did not present the form or direction of those constructed; but careful consideration, in the interval between the passing of the Act and the commencement of that part of the work, enabled the Author to improve the design in the manner carried out.

The form of these entrances is that of two short locks, the chambers of which were each originally designed to be 150 feet in length and 65 feet in width, fitted respectively with two pairs of ebb-gates, but without storm-gates, they being unnecessary, owing to the sheltered position of the openings and the absence of damaging seas.

An alteration was made to part of this design, at the pressing request of a leading member of the sailing-ship trade, who urged that the western lock should be 250 feet in length, instead of 150 feet. The object was to allow of the docking of sailing-ships earlier on the tide than under ordinary circumstances. The Author pointed out the impossibility of this being attained; but as the Dock Board considered that the alteration would not injuriously affect the working of the entrances, and that the additional expenditure would be comparatively trifling, it was agreed to, and the lock was carried out in its present extended form.

Though these entrances have been described as locks, they should, as far as the larger vessels are concerned, be only regarded as passages; the real lock of the system for such vessels being the half-tide vestibule into which the passages lead, known as the Langton Dock.

The main object for the double gates was security for the shipping; for where such an important system of docks, in use by the largest and most valuable ships in the world, is concerned, no reasonable precaution to insure their entire safety should be neglected. The value of this arrangement has been fully proved on two occasions by the serious damage to the inner gates through their being run into. The double gates also offer the further advantage of locks for the river craft ("flats"), which are here used in great numbers, and which play an important part in serving the large ocean steamers with bunker coal, and carrying goods from the canals, or such as are transhipped from other vessels.

A tug-steamer is provided by the Board, free of charge, for towing small craft between the entrances and the large vessels. These arrangements have the advantage of clearing the entrances and docks of small craft, some time before or after high-water, and thus admitting of the free and safe movement of the large ships to and from their berths.

The next point, and perhaps the most important for description, is that of the levels of the sills and approaches to the entrances, and the works by which they are maintained free from silt.

When the Author first took up his position as Engineer to the Dock Estate, it was generally accepted as practically impossible to maintain deep sills and approaches to the docks on the Liverpool side of the river.

Doubtless that was true as far as many of the southern docks were concerned, as the Pluckington Bank projects 4 or 5 feet above the level of low-water of spring-tides along the docks from the George's to the Brunswick, or a distance of 1½ mile. It was further urged that Liverpool, being on the lee side of the river, and the waters of the Mersey being highly charged with silt, deep sills were likely to be choked with sand, from the action of the on-shore winds and seas.

It may here be stated that the datum, to which all levels are referred in the Mersey, is the sill of the Old Dock, which occupied the site of the Pool where the custom-house now stands. The relation of this datum, known as "Old Dock Sill," to the Ordnance datum, is that the former is 4·67 feet below the latter. The levels of high and low waters of certain tides, derived from the record of the self-registering gauge at George's Pier, during the ten years, 1854–63, were:—

	Feet.	Ins.
Average H.W. of equinoctial spring-tides	21	1
" " spring-tides, including equinoctial tides	19	0½
" " " excluding " "	18	10
Mean H.W.	15	6
Highest H.W. of neap-tides	14	8
Average H.W. of ordinary neap-tides	11	7
Lowest H.W. of neap-tides	8	7
Mean-tide level	5	0
Highest L.W. of neap-tides	4	1
Liverpool datum, Old Dock Sill	0	0
Average L.W. of ordinary neap-tides	− 1	5
Lowest L.W. of neap-tides	− 3	10
Mean L.W.	− 5	6½
Average L.W. of O. S. T., exclusive of equinoctial tides	− 8	8
" " spring-tides, inclusive of equinoctial tides	− 8	10
Lowest L.W. of equinoctial spring-tides	−10	4

It will thus be seen of what vast importance deep sills are to the welfare of the port, and how desirable it is to obtain them.

The solution of this problem was an anxious and responsible duty, but the Author applied his experience gained in the construction of the deep-water entrances of the Morpeth and Alfred Docks, Birkenhead, to the docks at Liverpool, and he concluded that the sills of the New North Docks should be on the same levels as those at Birkenhead, viz., 12 feet below datum, or 2 feet below low-water of equinoctial spring-tides.

So important a departure from antecedent, and apparently well-matured conclusions, demanded elaborate and carefully thought out plans to provide for the maintenance of the required depths at all times, without dredging, or such like expedients. This was the main difficulty to be faced, for, as a matter of construction, sills could readily be laid at the level of 12 feet below datum; a system of dams would meet such a case. The area of the basin to be dealt with was about 9½ acres, and the area of the fairway within the splayed piers about 3½ acres. The Author concluded that the only certain method of effecting the object in view was by the flow of water through culverts of such form, and placed in such positions, as would command the areas in question.

This was attained by the construction of a system of culverts of large dimensions connected with the Langton Dock, having short branches fitted with sluices, and carried into the basin through the wing-walls; similar culverts and sluices were constructed through the masonry of the walls surrounding the island between the entrances. The culverts were for the most part of iron, having a special form of joint, and all were lined with a ¾-inch coating of Portland cement, kept in place by dove-tail ribs cast at near intervals on the inner surface of the pipes.

The whole system as finished, with its cement lining, presents a perfectly uniform and smooth conduit to the passage of flowing water.

The main feeders, or large pipes, were built behind the wing-walls, with the masonry of which the mass of concrete surrounding them was thoroughly incorporated. Their intakes from the Langton Dock were commanded by means of double clough-paddles of large dimensions, actuated respectively by hydraulic and hand machinery.

Water for sluicing can, as a rule, be drawn off without interfering with the working of the docks; in fact, as regards the Langton Dock, the running-off of water from it is a necessity of the mode of working, seeing that the water in it must, each tide, be lowered to suit the level of the next tide at two hours before high-water, when the gates have to be opened for the docking of ships.

Although at low neap-tides as much water as possible must be retained to give flotation to the vessels in the inner docks, yet, at the higher tides, water can generally be spared for sluicing, and it is then that the sluicing is most effective, owing to the lower level of low-water in the basin and fairway.

This sweeping is daily carried on, and has proved amply sufficient to prevent silt lodging in the immediate vicinity of the entrances, and for a limited distance outside the foot of the walls. It was evident, however, that such an expedient would be insufficient for dealing with those portions of the basin and fairway beyond the reach of the wall-sluices. To meet this want the Author devised a system of pipes, laid under the bottom of that part of the basin which it was necessary to keep clear, and which, to render the retention of silt more difficult, was covered throughout with a concrete floor.

These pipes were laid in trenches excavated in the clay to a depth of 18 feet below low-water level, bedded on, and surrounded with masses of concrete. The main pipes, 8 feet in diameter, are connected with the adjoining dock, and controlled by hydraulic and hand-paddles, in a similar manner to those already mentioned. They are fitted with short branches, with splayed openings or nozzles, leading upwards, and terminating about 9 inches below the finished concrete surface of the floor, and so spaced as to admit of the sluicing-water commanding the entire area of this part of the basin.

Upon these openings are laid heavily-framed disks of greenheart, connected to the pipe by four strong loose links of 2-inch iron. When in a quiescent state, these disks rest upon the opening of the upcast pipes; but when the paddles in the dock are lifted, they are forced up by the flowing water to the extent of the range allowed by the links, and thereby cause annular jets of water to fly out, sufficient to sweep a large circular area, and thus together clear the floor of the basin of sediment. This system has been in full and continuous work for eight years without the slightest mishap. Periodical examination has been effected by experienced divers, who report that the surface of the concrete is perfectly clean, and its face, as well as the lining of the pipes, in as good condition as when first put in. The only special rule in connection with the basin is, that no anchors are allowed to be let go within its area under a heavy penalty.

It now remains to describe how the immediate fairway outside the basin, and within the pier-heads, is kept deep and clear of banks or sediment.

The original level of the bed of the river in front of, and adjacent to, the Canada Basin, was much higher than that of the new sills for a considerable distance outside the river-wall. Artificial means of scouring a sufficient depth in the fairway to allow of the safe approach of large vessels, therefore, were evidently as much required for this position as for the interior of the basin.

The plan carried out is the following:—

The timber jetties, before referred to as projecting into the river from the north and south pier-heads, while they serve as guides or fenders against which vessels entering and leaving the basin may bear, also serve to limit the area within which deep water has to be maintained; and at the same time their foundations allow of the construction of a system of sluices for the removal of deposit in the vicinity of their outlets.

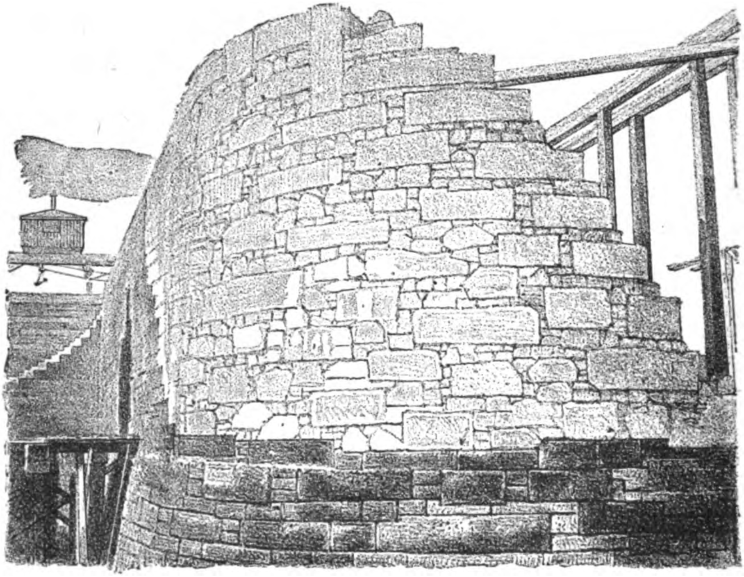
In the base of the north jetty three pipes, each 8 feet in diameter, are laid in connection with the main sluicing culvert, of 12 feet diameter, in the west wall of the basin. A series of sluicing outlets, 4 feet in diameter, 24 feet apart, project nearly horizontally from the 8-feet pipes, and the discharge from these outlets is regulated by clough-paddles in the basin pier-head. A similar series of outlets is laid in the north-west face of the south jetty, the supply of sluicing water being obtained in this case from the Canada Dock. The combined action of the discharge from these sluices and of the flow through the opening of the Canada Basin when its sluices are open, suffices to keep the fairway between the splayed piers at the required depth.

The south jetty is returned to the southward, parallel to, and at a distance of 180 feet from, the river-wall. At this distance the level of the foreshore is considerably lower than it is close into the wall. Sluices at intervals of 36 feet along the face are used to supplement the scouring power of the tidal current. A depth of water equal to that in the basin and fairway is always maintained along the face of the jetty, so that ships can lie alongside. The piers, being intended to bear any ordinary impact of the heaviest vessels, are of a very strong construction. The base, which is brought up to the level of the Old Dock Sill, is of concrete, containing the sluicing pipes, and the superstructure is of greenheart timber strongly framed together. The pier-heads and salient points are brought up in solid concrete.

Plate 2, with the foregoing explanations, will sufficiently demonstrate the general arrangements of the sluices and jetties.

The masonry of the wing-walls, island, and lock-chambers of this section of the work is faced with granite of the cyclopean class already described for the river-wall, but chisel-drafted and close punched on the face; it is coped with granite, also of irregular form and depth, and having, at short intervals, long stones tailed into the body of the wall. *Fig. 1* represents the character of the masonry. Cross section No. I, Plate 2, through the entrances, indicates the dimensions of the work. These entrances lead direct into the body of the Langton Dock.

Fig. 1.



The special size of the half-tide dock (18 acres) is due to the exceptionally heavy amount of work required to be done, in the passage of the largest class of steamships through it in a limited period of time. Its L shape has been necessitated to suit the peculiarities of the locality, and to admit of the convenient handling of vessels making use of the graving-docks and branch dock.

The total length of its quayage is 3,966 feet, and capacious and lofty sheds are constructed on its west and north sides, which shelter it from winds from these quarters, and are used for the discharge of vessels of the largest class. It is also connected by a

50 feet passage with the Brocklebank Dock, which the Author constructed before the Northern Extension was contemplated. By this means the new system of docks is linked with the old.

An important adjunct to the trade of the port is the graving-docks and repairing dock, which open out from the east quay of the Langton Dock. The graving-docks are two in number, with entrances 60 feet in width, and sills laid 6 feet below datum. The chambers are each 950 feet in length, subdivided about midway by piers and gates, by which means the inner chambers may be used as "long time," and the outer as "short time" docks.

On the quay between the two docks, and about the centre of their length, a 30-ton hydraulic crane of a novel type is provided. It is arranged to travel on rails, one rail fixed at the dock coping, and the other in the centre of the quay, so that it may be moved to any desired point within its range of travel. The central rail serves for the crane when alongside either dock. When it is required to move the crane from one dock to the other, its back end is fixed on a pivot, at one end of the track, while its front wheels travel on a circular roller path. The range of fore-and-aft travel is such as to allow of its use in any of the four chambers of these graving-docks. The travelling of the crane on its rails is effected by hydraulic capstans hauling on wire ropes. This crane has been found of great value to the trade for handling heavy screws, bosses, or pieces of machinery, which formerly had to be dealt with by sheers, or temporary expedients of that character.

With the exception of the piers and copings, all the works in these graving-docks, including altar courses and bottom, are of concrete laid in bulk, the proportion being 1 part of Portland cement, and 8 parts of clean shingle, gravel, and sand for the body of the work, the face being a mixture of 6 to 1. They have now been in full use ten years, and are as good as, if not better than, when first completed.

Adjoining the graving-docks to the north is the branch dock, designed for repairing and overhauling purposes; the exigencies of trade, however, have been so pressing as to require the use of the greater part of its quays for cargo purposes. The length of the dock is 893 feet, with a width of 140 feet, sufficient for the purpose for which it was designed, but not for general trade, which needs more space for berthing river craft and coal barges alongside the ocean-going steamers. The width of the entrance is 60 feet, with a sill laid at a level similar to those of the river entrances.

Its southern quay is fitted with a crane, capable of lifting 100 tons, of novel design, it being arranged to lift the loads by a piston-rod of an inverted hydraulic cylinder, pendent from the jib-head. From the quay level to the jib-head, its height is 120 feet, with a projection of 35 feet beyond the line of the coping, sufficient for ships of the broadest beam. The stroke of the piston, that is, length of lift of the crane, is 50 feet. The design and structural work of the crane were by Messrs. Sir W. G. Armstrong and Co., of Elswick.

The underground foundation is formed of a solid square pier of concrete, brought up from the rock to the quay level, above which it takes the form of a circular pier, also of concrete, and carried up 20 feet above the surface of the quay. This pier is finished by a substantial coping of granite, upon which is laid a heavy steel roller-path.

The crane is particularly suitable for heavy weights where perfect control and nice adjustment are necessary. It lifts the heaviest boilers with ease, its working has hitherto proved eminently satisfactory, and its form and characteristics impart confidence.

Lines of rails of a substantial character are laid in connection with the crane, and in full communication with those of the different railway systems of the country.

Between the graving-docks, and near their entrances, an engine-house, Plate 4, has been erected, which is the centre of power for the whole of the work of this section of the estate.

It is a large building of brick, with sandstone dressings, and contains the pumping-engines for draining the graving-docks, the main hydraulic engines for working the gates, bridges, sluices, capstans, and cranes, as also for giving off whatever supplementary power may be found requisite for working movable jiggers, roof cranes, grain-machinery, and such like appliances for the proper equipment of a dock system of this character. The boilers and accumulator are in the same block of buildings; the latter in a tower attached to the main building.

Groups of convenient dwellings have been provided over the engine-houses for the use of the four men in permanent charge, and for a leading foreman. As the quay-space in this locality was limited, and separate cottages inadmissible, this arrangement was devised in order to ensure those in charge of this important machinery, which is running almost constantly, being at all times at hand. It has worked well, and the arrangement is much appreciated by the men whose time and comfort have been thus regarded.

The pumping-machinery for emptying the graving-docks of water is situated in the west compartment of the building, and consists of two independent horizontal condensing Corliss-valve engines, each having one cylinder 26 inches in diameter, and of 4 feet stroke. Each engine is arranged to drive the pumps in one well. The wells, two in number, each 16 feet by 10 feet, are situate on the north and south sides of the engine-house at its west end, and the culverts are arranged so that each graving-dock can be drained into one well, or both wells can be used for draining one or both graving-docks.

The range of tide at Liverpool permits of the water from its graving-docks generally being run off with the tide. In the case of the Langton Graving-Docks, two culverts, each 5 feet in diameter, are laid from the graving-docks along the south and south-east walls of the Langton Dock, and discharge into the Canada Basin from its east wing-wall. These culverts are used for emptying the graving-docks on ordinary tides; but in case of neap-tides, or when it is desired to drain the dock of water more quickly than running off would allow, the pumps are brought into requisition.

The main pumps are of the horizontal centrifugal or turbine type, with a fan 5 feet in diameter, driven by gearing from the Corliss engine above referred to. The leakage from the graving-docks, which is comparatively small in quantity, and has to be lifted through a great height, is dealt with by chain-pumps of the ordinary pattern, also driven by gearing from the main engines.

The engines and centrifugal pumps were designed and constructed by Messrs. Hick, Hargreaves and Co., of Bolton, and have been in full work for eight years, without giving trouble, or causing any undue expense in maintenance.

The hydraulic engine, situated in the east end of the building, is by Messrs. Sir W. G. Armstrong and Co., and was, at the time of construction, the largest of that class of engine then carried out by that firm. It is a horizontal direct-acting surface-condensing engine, having two steam-cylinders each 33¼ inches in diameter, and of 5 feet stroke, and is capable of giving off 350 HP. The force-pumps are 8 inches each in diameter. The accumulator is 24 inches in diameter, and has a stroke of 40 feet. The boilers, five in number, with a Green's economiser, are located between the pumping and hydraulic engines. They are wrought-iron boilers of the Lancashire type, and were supplied by Messrs. George Forrester and Co., of Liverpool.

The general arrangements are shown in Plate 4.

The masonry of the Langton Dock and branch, is of red sandstone, having horizontal and vertical joints; but with broken courses as opposed to the ordinary continuous coursed work. The Author has adopted this class of work throughout the docks as being cheaper, and in his judgment, stronger than ordinary masonry with gauged courses, which involves difficulties and waste in quarrying, and consequent additional cost. The backing of the walls is mainly of heavy sandstone blocks, with the spaces filled up with concrete. The coping is of granite. The general form and dimensions of these walls are shown by Plate 3.

The passages leading from the Langton to the Alexandra Dock are two in number, each 60 feet in width, and having sills laid at the same level as those of the river entrances. The sills of the entrances and passages are in the form of very flat inverts, the rise being in the case of the 65 feet entrances not more than 36 inches, and this in order to suit the flat floors of most modern ships. The masonry of the side walls of these passages is similar in character to that already described for work in like positions.

The Alexandra Dock was designed to accommodate the largest steamers, and has, therefore, special features to meet their requirements. Its length from the entrances to its northern extremity, is 1,600 feet, the west wall being of that length, without break; the width of the body of the dock is 500 feet. On the eastern side are arranged three large branch docks, 1,430 feet, 1,380 feet, and 1,200 feet in length respectively, each 300 feet wide. Its walls are of red sandstone masonry, of a similar character to that already described, coped with irregularly bedded granite, and to a great extent similar in section to that of the Langton Dock. The total area of the dock is 44 acres, with quayage amounting to 11,814 feet.

The quays are surrounded by substantial sheds 95 feet in width, Plate 3, built of brick, with single-span roofs of timber, the principals having timber backs and wrought-iron tie-rods. They are covered with "Vieille Montagne" zinc, adopted for the sake of lightness.

Opening out of the Alexandra Dock, at a point adjoining its north-west angle, is the Hornby Dock, the passage into which is 50 feet in width, with a sill laid at a similar level to those of the several entrances of this system. This, the most northerly dock on the estate, running east and west for a length of 1,620 feet and being 425 feet wide, was designed and constructed to meet the requirements of the timber trade. It has, therefore, been provided with quays of special dimensions; that on the north has its coping laid at the level of 21 feet above datum, and is paved in the form of a long incline at a slope of 1 in 60, 300 feet in width, beyond which is the permanent timber storage ground.

This arrangement facilitates the landing of log timber through the bow-ports of the timber-ships, which are moored end on to the quays. The quays around the other sides of the dock are at the ordinary level, namely, 27 feet above Old Dock Sill datum.

The southern quay of this dock has been constructed 200 feet in width for facilitating the storage of deals. The west quay is of the ordinary type, 220 feet in width, having a short, narrow inlet dock at its northern extremity, in the form of a slipway, used for the removal of wreck or raft-timber from the body of the dock. The whole of this west quay is flanked by a shed 95 feet in width, extending along the margin of the inlet dock, chiefly for the purpose of additional shelter. The berth is largely frequented by the smaller class of steam-ships with ordinary cargo, chiefly cotton, for which it is very convenient.

All the quay walls surrounding this dock are of concrete, and of a special sectional form, Plate 3. They are built with rusticated longitudinal joints, a form adopted for facilitating construction, while at the same time adding to the sightliness of the work without increase of cost. No difficulty or failure has been experienced in any part of the concrete work. The concrete was mixed and deposited *in situ*, the proportions being 8 parts of broken stone, gravel, and sharp sand, to 1 part of Portland cement of carefully selected quality, with a facing containing a somewhat larger portion of cement.

The excavations included in this section of the work consisted chiefly of strong boulder-clay, overlaid by a thin coating of sand. The total amount removed to the depth of about 14 feet below datum was about 6,000,000 cubic yards. A large quantity of good brick-clay was obtained, from which over thirty million bricks have been made and used in the various sheds, warehouses, and other buildings since constructed. The work was executed by contract, by Mr. Charles Tottenham.

The several gates, cloughs, paddles, &c., as well as the timber jetties, were built entirely of greenheart timber, put together with galvanized iron bolts.

The whole of the work, other than the excavations and engines, was carried out by the Dock Board's workmen, acting under the instructions and control of the Author.

In order to afford complete shelter to shipping in the docks during heavy on-shore gales, high screens of open timber-work were erected across certain of the roadways, thus baffling the force of the winds without impeding the traffic, as proper gateways were left through them in convenient positions. At one large opening, abreast of the passage-way between the Langton and Alexandra Docks, the wind sometimes made it difficult for large ships with high freeboards to pass through without inconvenience and delay, and the Author therefore constructed a building on the margin of the river-wall immediately to windward of the passage in question; this, with the adjoining screen, effectually breaks the force of the wind, and obviates the difficulty complained of. The erection has been let at a rental sufficient to recoup the interest on the outlay, and is found of great value as a coffee-palace for the workmen in the locality, exposed as it is, and somewhat remote from town. A portion of the building is used as an engine-house for driving electric-lighting machinery.

The pier-heads of the jetties, and several entrances and passages are provided with electric arc-lights of 2,000 candle-power each, carried on masts of lightly-framed ironwork, 80 feet in height. These lights are brought into use during tide-time, for about three hours at a time, when ships are being moved in the docks, and have been found of great use in expediting that important operation. The rest of this portion of the estate is lighted in the ordinary manner by gas.

The Langton Dock and branch, with the river entrances, as also the graving-docks, and Alexandra Dock, with its surrounding sheds, were completed in 1881, and were opened by their Royal Highnesses the Prince and Princess of Wales, on the 8th of September of that year. The Hornby Dock was completed in 1883, and came into use immediately afterwards.

The total estimated cost of these north works amounted to £2,727,000. Since their completion they have accommodated regularly sea-going ships of the largest class, with an aggregate of about 18,000,000 tons, and bringing in a gross revenue to the estate of £2,500,000.

The remaining work to be described, comprised under the Act of 1873, is that section situated near the southern extremity of the Dock Estate, at a distance of 5 miles up river from the northern boundary at Rimrose.

One of the first works undertaken by the Author, on his appointment, was to design and construct a small half-tide dock in this position, with two graving-docks opening out of it. These were called the Herculaneum Docks, they having been built on the site of an old pottery of that name.

The half-tide dock was then designed to form part of a larger and more comprehensive scheme, since developed, under the Act of 1873, into the present system, which is of considerable magnitude, having, like the docks at the north end, deep sills throughout.

The ground at the southern end of the Dock Estate was physically dissimilar to that at the north, there being a comparatively narrow strip of low land stretching along the river front, rising transversely to the eastward somewhat abruptly. Between the Brunswick Dock and the Herculaneum, the general level of the surface of the ground was not many feet higher than the ordinary coping, the high land being some distance inland from the site of the new docks; but at the Herculaneum Dock the construction of the works involved the cutting down of the slope of the hill, which, at its highest point, was about 70 feet above the present level of the quay.

The whole of this district is of the New Red Sandstone formation, but mostly of immature rock, which, however, was so dead and tough, as only to be excavated by blasting. This was a tedious and costly operation, the more so as there was no possibility of getting rid of the surplus material in the useful way of filling, &c.; the Author was therefore unwillingly compelled to undertake the costly device of sending it to sea, about 10 miles outside the bar, and depositing it in deep water over a large area, the site of which, as a place of deposit, was approved by the Admiralty. The total excavations thus dealt with amounted to over 1,000,000 cubic yards. To effect this five hopper-barges were constructed, having a capacity of 500 tons each, at a cost of about £40,000. These barges, since the excavations have been completed, have been usefully turned to account to convey to sea the large quantity of dredgings daily removed from the docks, and now required by the Conservator of the Mersey to be deposited outside the river, so that their cost to the works may be considered as written off.

The shape of the half-tide dock as extended is that of an inverted L, having its eastern limb stretching in a southerly direction, and forming a narrow inlet dock affording useful quayage, and a means of communicating with the Board's land still further south, when the time comes for utilizing this portion of the Estate. The length of the dock from east to west is 810 feet, and its width from north to south 430 feet. The length of the branch dock is 800 feet, width 120 feet, and total area of the dock and its branch 9¾ acres.

At the base of the cliffs, on the east and south sides of the Herculaneum Dock, chambers have been excavated in the solid rock; for the special purpose of affording a safe and convenient means of storing petroleum in barrels. These petroleum magazines are each 50 feet long, 20 feet wide, and 19 feet high to the soffit of the rock arch. Each magazine is separated from its neighbour by a wall of solid rock 5 feet thick. They are faced in concrete, and have impervious sills, built to the level of 4 feet above the floor, so forming receptacles, each capable of containing the whole contents of the barrels stored in it. All danger of the liquid oil flowing on the adjacent quays, in case of accident, is thus avoided, and from the general construction the risk of fire spreading is small. The magazines are capable of containing 60,000 barrels of petroleum in the whole. Lines of railway are laid in front of them.

Three graving-docks project from the south quay of the Herculaneum Dock in a southerly direction. Their chambers are each about 760 feet in length, with 60 feet width of entrance, and sills laid 4 feet below datum. Two of them, built by the Author in 1865, are of Runcorn stone, coped with limestone, the whole being excavated out of the sandstone rock. The third, built recently, is entirely of concrete coped with granite. Drainage arrangements had to be provided to relieve the masonry and concrete from the upward pressure of the water with which the rock was charged. The result has been that the chambers are fairly dry, especially that of the concrete work.

These graving-docks are emptied of water by means of chain-pumps driven by a locomotive engine temporarily adapted for the purpose, and situated in an engine-house adjoining the entrances, which also contains engines for working the hydraulic machinery of this part of the system, and for electric lighting.

The walls of the half-tide dock are of sandstone, except in the fairway of the entrances and passages, where they are built of granite of cyclopean character.

The river entrances are two in number, and have been designed with as much obliquity to the tidal streams of the river as the position would permit. Their widths are 80 feet and 60 feet respectively, and the sills are now laid 12 feet below datum. Originally they were 8 feet below datum; but after experience of the working of the 12-foot sills at the north end, the Author felt justified in reconstructing these at the same depth.

The change of depth involved an extended deepening of the foreshore and fairway, which, in this position, is all of rock. It further involved a system of sluicing, similar in principle to that carried out at the entrance to Canada Basin; but the jetty and culvert work in this case are immediately in front of, and parallel to, the river-wall.

The main culverts are of iron, similar to those at the north end, 7 feet 9 inches in diameter, ribbed and lined with cement; the outlets are 3 feet 4½ inches by 2 feet 7 inches, and during sluicing they are kept open in groups of six at a time. The culverts are connected with the Herculaneum Dock, from which, and the adjoining docks, the supply of sluicing water is obtained, by a 12-foot masonry conduit fitted with hydraulic paddles.

The sluicing operations in connection with these works have been in force for about four years; and though difficulties have at times occurred in obtaining a sufficiency of sluicing water, owing to the incompleteness of the inner docks, it is evident that the appliances will be able to keep the entrances and fairway clear of sediment to the extent anticipated by the Author.

The chain of new docks, worked in connection with this dock, owing to the narrowness of the estate in the locality, extends in a northerly direction parallel with the river, in lieu of east and west as at the north end. The first dock is the Harrington, approached through a 60-foot passage, with a sill laid 12 feet below datum. The length of the dock is 1,300 feet, and width 300 feet, with a water area of over 9 acres; its western quay is 200 feet in width, absorbed by a shed 143½ feet wide, with a roadway to the westward of the same. Its eastern margin, which ranges from 130 to 150 feet in width, is occupied by a double-storey shed (Plate 3) flanked by a paved roadway, laid with a double line of rails. The rails extend throughout the whole of the estate, and are connected with the several railway systems abutting upon its margin.

A double-story-shed was adopted in this position by reason of the comparative narrowness of the quays flanking this portion of the estate. In order to overcome the difficulty and cost of working the upper floor, and to assimilate it in convenience to a wide floor at the quay level, the Author has adopted a special form of crane, the frame of which rests upon and travels along the ridge of the roof, and the outer wall of the shed, the jib having a long rake, and spanning sufficiently over the edge of the quay to command the hatchways of any ship. The craneman works the machine from a house pendent to the lower part of the frame, so that he has a complete view of the work to be done. There are eight cranes on this shed; all of which are worked by hydraulic power.

The crane is capable of lifting 30 cwt., and it can effect 60 lifts per hour to the upper floor, the cost of raising through the extra height being inconsiderable. As many as 520 lifts have been effected by one crane in nineteen working hours, and these could have been largely increased, were it not for the delay in breaking out the cargo from the hold of the vessel.

The length of double-story sheds lately erected and worked by these appliances, is 3,040 feet, and the number of cranes twenty, commanding an aggregate area of quay and upper floor space equal to 13 acres. Though the double-story sheds, with upper floors capable of sustaining a load of 30 cwt. per square yard, are necessarily of somewhat expensive character, their cost per square yard of floor is but slightly greater than that of the ordinary ground-floor sheds, and if the saving in land is considered, the cost would be less than that of the single-story sheds.

The next in the chain of docks of the New Southern System is the Toxteth Dock, opening from the Harrington, through a 60-foot passage, with a 12-foot sill, and extending in a northerly direction for a length of 1,450 feet; its width, at the southern extremity, is 300 feet, and at the northern end 380 feet. At the north-west corner of the dock is a lock 177 feet in length and 50 feet wide, with an 8-foot sill. It leads to the river, and is used as a means of convenient ingress and egress for the smaller class of craft using the system, and thus relieves the main entrances from part of the work. The western quay is 250 feet in width, and along it for its entire length is a single-story shed 150 feet in width, with double-span roofs; this is the widest and most extensive shed on the Dock Estate, having a ground area of 4¾ acres. The eastern quay is 156 feet in width, of which 95 feet are occupied by a double-story shed, having an aggregate floor area of 6 acres, and provided with nine hydraulic roof-cranes, of the capacity and dimensions already described for the Harrington Dock.

This dock, recently opened, is not entirely completed, though it has already given evidence of coming into active use; several large ships have effected rapid discharge and loading on both its eastern and western quays.

Further power being required to work this part of the system, the Author has arranged for the construction of a new hydraulic installation on the quay adjoining the north-eastern angle of the dock. The engines, which are to be supplied by Messrs. Sir W G. Armstrong, Mitchell and Co., of Elswick, are to be of 200 HP., with an accumulator 20 inches in diameter, and of 35 feet stroke; steam will be obtained from two steel Lancashire boilers working up to 100 lbs. pressure per square inch, to be made by Messrs. Foster and Sons, of Preston.

Opening out of the north-east angle of the Harrington, by a 60-foot passage and 12-foot sill, is a narrow dock called the Union Dock, so named from its forming the connection by means of a 60-foot passage with the Brunswick Dock.

The Union Dock, which is 450 feet in length and 125 feet in width, is designed to serve as a lock, and will play an important part between the new and old systems. Through it vessels, which cannot on neap-tides, by reason of their deep draught, get into the river over the Pluckington bank and shallow sills of the old docks, are enabled, by a system of artificial deepening by pumping, to dock and undock through the chain of new docks into the river, by the Herculaneum entrances; thus practically placing the old docks, which were to some extent falling out of use, on a par with the new and deeper system. This improvement by pumping will admit of several of these older docks being brought into prominent use, thus adding largely to the working capacity of the estate. Superior sheds will be provided on some of the quays. The subject, however, is so important and has so many features of interest as to require a Paper in itself.

In view of the character of the foundation on which the southern docks were built, a masonry wall was allowed for in the original design, but in maturing the plan, the Author adopted a method by which a very sound system of "veneering" the sandstone rock was carried out, without any attendant dangers, such as usually result from that class of construction.

The plan adopted was as follows:—

The rock was cut down to a nearly vertical face at a distance of 2 to 4 feet behind the face line of the stonework, with which it was to be veneered. At distances of about 20 feet apart along the line of the wall, excavations were made from coping to foundation levels in the form of counterforts. They were 5 feet in width, 4 feet in depth, and were dovetail in shape from top to bottom. Into these were inserted large blocks of ashlar, also cut dovetail, so as to fit the excavated chamber, and shaped dovetail outwardly, to interlock the masonry panels which intervened between the counterfort stones. The whole of this facing work is of sound selected stone, and presents to the eye a wall of ordinary character, and is so interlocked and held in place by the fantail jointing, that no possible failure of the panels can occur. The greater portion has been in use for several years, without the slightest sign of failure or movement.

This wall is illustrated on Plate 3.

The parliamentary estimate for the whole of the south works was £1,373,000, and it is expected that they will be completed well within this amount.

By the northern and southern extensions, which the Author has endeavoured to describe, additions have been made to the area of docks belonging to the Mersey Docks and Harbour Board at Liverpool, amounting to 44 per cent. of the total area of 252 acres existing at the time of the passing of the Act of 1873; and as the new docks were specially designed for, and are being used by, the largest vessels trading to the port, the tonnage worked per acre, or per yard of quay berthing, is, of course, much higher than in the case of the older docks.

Appended is a statement showing the names, areas, and quayage of the docks in 1873, and of the new docks, and in addition, giving other particulars relating to the Dock Estate.

The Paper is accompanied by sixteen drawings and tracings and four photographs, from which Plates 1, 2, 3 and 4, and the *Fig.* in the text, have been engraved.

APPENDIX.

LIVERPOOL DOCKS.

Docks in the Year 1873.

Docks.	Position and Width of Entrance or Passage.			Sill below Datum.		Coping at Hollow Quoins above Datum.[1]		Water-Area.		Lineal Quayage.	
		Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Acres.	Yds.	Miles	Yds.
Brocklebank Dock . .	South	80	0	7	9	28	0	11	1,010	0	1,002
„ Lock, 110 feet long	North	32	0	6	0	28	0				
	West Mid.	20	0	6	0	28	0				
	South	60	0	7	9	28	0				
North Carriers' Dock .	West	40	0	6	0	27	0	2	3,423	0	641
South „ „ .	West	40	0	6	0	27	0	1	4,515	0	615
Canada Dock . . .	South East	50	0	6	6	29	0	17	4,043	0	1,272
	West	80	0	6	6	29	0				
„ Lock, 498 ft. long	North	100	0	7	9	28	0	1	3,479	0	487
Huskisson Dock . . .	..			..		..		14	3,451	0	939
„ Lock, 338 ft. long	South East	80	0	6	6	26	0	0	4,682	0	342
Huskisson Lock, 363 ft. long	West	45	0	6	0	26	0	0	3,650	0	330
Huskisson Branch Dock, No. 2	..			..		..		8	780	0	890
Huskisson Branch Dock, No 1	..			..		..		7	592	0	910
Sandon Dock . . .	West	70	0	6	6	30	11	10	100	0	867
Wellington Half-Tide Dock	North East	70	0	6	9	30	9	3	813	0	400
	West	50	0	6	6	28	0				
Wellington Dock . .	West	70	0	6	6	31	0	7	4,120	0	820
Bramley-Moore Dock .	North	60	0	6	0	26	0	9	3,106	0	935
	South	60	0	6	0	26	0				
Nelson Dock	South	60	0	6	6	26	0	7	4,786	0	803
Canal Basin, Lightbody Street.	West	18	0	O.D.S.		26	0	0	920	0	110
				Above.							
Stanley Lock . . .	West	18	0	2	6	29	0				
Collingwood Lock .	West	18	0	2	6	26	0				
Salisbury Lock . .	West	18	0	..		26	0				
	Inner Sill			2	6	..					
				Below.							
	Outer Sill			5	0						
Stanley Dock . . .	West	51	0	5	8	29	0	7	120	0	753
Collingwood Dock . .	West	60	0	6	9	26	0	5	244	0	553
Salisbury Dock . . .	West North	60	0	6	11	26	0	3	2,146	0	406
	South	50	0	6	11	26	0				
Clarence Graving Dock Basin	North	45	0	4	9	26	0	1	1,056	0	291
	South	44	6	4	6	26	6				
Clarence Half-Tide Dock	West	50	0	5	0	26	8	4	1,794	0	635
„ Dock . . .	West	47	0	3	2	26	0	6	273	0	914

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[1] The datum is the level of the Old Dock Sill which is preserved on a tide-gauge at the west side of the centre pier of the entrances to the Canning Half-Tide Dock.

LIVERPOOL DOCKS.—DOCKS in the YEAR 1873—*continued.*

Docks.	Position and Width of Entrance or Passage.			Sill below Datum.		Coping at Hollow Quoins above Datum.		Water-Area.		Lineal Quayage.	
		Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Acres.	Yds.	Miles	Yds.
Trafalgar Lock . . .	North	45	0	6	7	23	10	0	2,937	0	256
„ Dock . . .	North	44	3	6	7	21	11	5	4,546	0	764
Victoria Dock . . .	North	45	0	4	11	21	11	5	3,559	0	755
	South	50	0	6	6	26	0				
West Waterloo Dock .	South	60	0	8	0	22	1	3	2,146	0	533
East „ „ .	South	60	0	8	0	22	1	2	3,375	0	506
Prince's Half-Tide Dock	West North	65	0	8	0	31	0	4	3,250	0	429
„ Lock, 110 ft. long	Mid.	32	0	8	0	31	0				
„ „ „	South	65	0	8	0	31	0				
Prince's Dock . . .	North	45	0	5	11	27	5	11	1,490	0	1,178
George's Dock . . .	..			..		..		5	154	0	645
George's Dock Passage	North	36	0	4	6	24	5	0	2,439	0	356
	South	40	3								
Manchester Dock . .	West	32	10	Above. 0	3	23	3	1	595	0	339
„ Lock, 86 feet long	West	33	8	Below. 3	9	24	3	0	315	0	57
Canning Dock . . .	West	45	0	6	1	26	2	4	376	0	585
Canning Half-Tide Dock	West North	45	0	6	3	28	3	2	2,688	0	429
	South	45	0	6	3	28	3				
Albert Dock	North	45	0	6	4	26	0	7	3,542	0	885
	East	45	0	6	0	26	0				
Salthouse Dock . . .	North	45	0	6	0	26	0	6	2,019	0	784
Wapping Basin . . .	North	50	0	5	8	26	0	1	3,151	0	454
	South	50	0	6	0	26	0				
	West	40	0	6	0	25	0				
„ Dock . . .	West	50	0	6	0	26	0	5	499	0	815
	South	50	0	6	0	26	0				
King's Dock	South	42	0	5	0	26	1	7	3,896	0	875
Queen's Half-Tide Dock	West North	70	0	6	9	31	0	3	3,542	0	445
	South	50	0	6	9	31	0				
„ Dock . . .	West	50	0	6	0	26	0	10	1,564	0	1,214
	South	60	0	6	6	28	9				
Coburg Dock . . .	West	70	0	6	0	30	6	8	26	0	1,053
Brunswick Dock . .	North	60	0	6	6	27	0	12	3,010	0	1,086
	West	42	0	5	6	26	0				
„ Half-Tide Dock	West	45	0	6	0	26	6	1	3,388	0	491
Total water-area and quay-space of the Liverpool Docks, 1873								251	2,339	17	1,053
Trafford Dock and Lock (purchased 1876) . .	Outer	30	0	Above. 0	3	25	3	0	4,102	0	419
	Inner	30	0	1	3	26	0				
Total water-area and quay-space of the Liverpool Docks, 1876								252	1,601	17	1,472

LIVERPOOL DOCKS—*continued.*—EXTENSIONS UNDER the ACT of 1873.

Northern Extension.

Docks.		Position and Width of Entrance or Passage.			Sill below Datum.		Coping at Hollow Quoins above Datum.		Water-Area.		Lineal Quayage.	
			Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Acres.	Yds.	Miles	Yds.
Hornby Dock . . .		South	50	0	12	0	27	0	16	3,769	0	1,430
„ Branch Dock .		South	50	0	O.D.S.		27	0	0	3,354	0	308
Alexandra Dock . .	South	East	60	0	12	0	27	0	17	4,055	0	1,085
		West	60	0	12	0	27	0				
„ Branch Dock, No. 3		..			..		..		7	3,420	0	846
Alexandra Branch Dock, No. 2		..			..		..		9	2,657	0	1,024
Alexandra Branch Dock, No. 1		..			..		..		9	573	0	983
Langton Dock . . .		S. East	50	0	9	0	27	0	18	589	0	1,322
„ Lock, 238 ft. long	South	West	65	0	12	0	30	0	0	1,719	0	160
„ „ 119 „		East	65	0	12	0	30	0	0	860	0	81
Langton Branch Dock .		West	60	0	12	0	27	0	2	4,549	0	671
Total water-area and quay-space of the New North Docks									83	1,345	4	870

Southern Extension.

Docks.		Position and Width of Entrance or Passage.			Sill below Datum.		Coping at Hollow Quoins above Datum.		Water-Area.		Lineal Quayage.	
			Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Acres.	Yds.	Miles	Yds.
Canal Dock, East of Brunswick Dock (less Railway Co.'s portion)		West	25	0	1	0	27	0	0	4,635	0	450
Brunswick Dock, area added		..			..		..		0	354		
Union Dock		North	60	0	6	6	27	0	1	1,941	0	361
		South	60	0	12	0	31	0				
Toxteth Dock . . .		South	60	0	12	0	31	0	11	1,075	0	1,134
„ Lock, 177 ft. long		West	50	0	8	0	31	0	0	1,013	0	118
Harrington Dock . .		South	60	0	12	0	31	0	9	256	0	1,023
„ Lock, 131 ft. long		West	22	0	5	9	31	0	0	320		
Herculaneum Dock . .	West	North	80	0	12	0	31	0	7	2,581	0	596
		South	60	0	12	0	31	0				
„ Branch Dock		..			..		..		2	853	0	577
Total water-area and quay-space of the New South Docks									32	3,348	2	739

Deduct docks absorbed in New South Docks.	Water Area. Acres.	Yards.	Lineal Quayage. Miles.	Yards.	Acres.	Yds.	Miles	Yds.
Brunswick Dock, quay absorbed . . .	..		0	12				
Toxteth Dock . . .	1	469	0	393				
Harrington Dock . .	0	3,740	0	315				
Herculaneum Half-Tide Dock . . .	3	3,000	0	416				
					5	2,369	0	1,136
Net additional water-area and quay-space of the New South Docks provided under Act of 1873					27	979	1	1,363

SUMMARY. LIVERPOOL DOCKS.

——	Water-Area.		Lineal Quayage.	
	Acres.	Yards.	Miles.	Yards.
Total in 1876	252	1,601	17	1,472
Net aggregate of dock extension under Act of 1873	110	2,324	6	473
Total in 1889 . . .	362	3,925	24	185

LIVERPOOL BASINS.

——	Width of Entrance.		Height of Piers above Datum.		Water-Area.		Lineal Quayage.	
	Ft.	Ins.	Ft.	Ins.	Acres.	Yards.	Miles.	Yards.
Canada Basin	390	0	N30 S32	0 0	9	2,805	0	846
Sandon Basin	200	0	31	0	6	904	0	702
George's Ferry Basin . .	67	0	23	8	0	1,344	0	160
Chester Basin	36	0	22	2	0	2,568	0	288
Anderton Basin . . .	46	0	25	7	0	1,422	0	175
Eagle Basin	50	0	25	10	0	3,991	0	260
South Ferry Basin . . .	60	0	30	6	0	2,927	0	205
Total water-area and quay-space of the Liverpool Basins					18	1,441	1	876
Total water-area and quay-space of the Liverpool Docks					362	3,925	24	185
Total					381	526	25	1,061

Birkenhead Docks.

Docks.	Position and Width of Entrance.			Sill below Datum.		Coping at Hollow Quoins above Datum.		Water-Area.		Lineal Quayage.	
		Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Acres.	Yds.	Miles.	Yds.
West Float	East	100	0	7	6	26	6	52	319	2	210
Basins near Canada Works											
West Basin . . .	North	50	0	..		..		1	2,554	0	543
East „ . . .	North	50	0	..		..		1	84	0	390
East Float	..			..		..		59	3,786	1	1,506
Corn Warehouse Dock .	South	30	0	O.D.S.		26	0	1	453	0	555
Railway Companies' Basin	..			..		..		0	606	0	113
Wallasey Dock . . .	..			..		..		12	3,813	0	1,261
				Below.							
Passage to Do. . . .	West	49	2	9	0	26	0	0	1,333	0	234
Inner Northern Entrances	North	100	0	9	0	26	0		..	0	242
Lock, 198 feet long .	Middle	30	0	..		26	0	0	667	0	264
Inner Sill . . .	..			9	0						
Outer „	..			12	0						
Lock, 274 feet long .	South	50	0	..		26	0	0	1,522	0	300
Inner Sill . . .	..			9	0						
Outer „	..			12	0						
Alfred Dock	..			..		..		8	2,922	0	482
Outer Northern Entrances											
Lock, 348 feet long	North	100	0	12	0	31	0	0	3,888	0	352
„ 198 „ .	Middle	30	0	12	0	26	0	0	667	0	377
„ 398 „ .	South	50	0	12	0	26	0	0	2,222	0	391
Egerton Dock	West	70	0	7	4	25	0	3	4,011	0	754
Morpeth Dock . . .	West	70	0	5	5	25	0	11	2,404	0	1,299
„ Lock, 398 ft. long	East	85	0	12	0	26	0	0	3,777	0	441
Railway Company's Basin	South	25	0	O.D.S.		26	0	0	3,144	0	319
Morpeth Branch Dock .	West	85	0	..		26	0	4	243	0	637
Total water-area and quay-space of the Birkenhead Docks								159	4,535	9	110

Birkenhead Basin.

——	Width of Entrance.		Height of Piers above Datum.		Water-Area.		Lineal Quayage.	
	Ft.	Ins.	Ft.	Ins.	Acres.	Yards.	Miles.	Yards.
North Basin	500	0	31	0	4	2,843	0	669
Total water-area and quay-space of the Birkenhead Basin					4	2,843	0	669
Total water-area and quay-space of the Birkenhead Docks					159	4,535	9	110
Total					164	2,538	9	779

Total Area of the Liverpool and Birkenhead Docks and Basins.

	Acres.	Yards.	Miles.	Yards.
Total water-area and quay-space of the Liverpool docks and basins	381	526	25	1,061
Total water-area and quay-space of the Birkenhead docks and basin	164	2,538	9	779
Total	545	3,064	35	80

LIVERPOOL GRAVING-DOCKS.

Name and Position.		Width of Entrance.		Sill below Datum.		Coping at Hollow Quoins above Datum.		Length of Floor.		Total Length of Floor.	
		Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.
Langton, No. 1 (South) .	Outer	60	0	6	0	27	0	448	0		
	Inner	60	0	6	0	22	0	500	0		
„ „ 2 (North) .	Outer	60	0	6	0	27	0	500	0		
	Inner	60	0	6	0	22	0	448	0		
										1,896	0
Huskisson Lock as a graving dock		80	0	6	6	26	0	..		395	0
Sandon, No. 1 (East) . .		60	0	3	6[1]	26	0	565	0		
„ „ 2		70	0	3	6[1]	26	0	565	0		
„ „ 3		60	0	3	6[1]	26	0	565	0		
„ „ 4		70	0	3	6[1]	26	0	565	0		
„ „ 5		45	0	3	6[1]	26	0	565	0		
„ „ 6 (West) . .		45	0	3	6[1]	26	0	565	0		
										3,390	0
Clarence, No. 1 (North) .	Outer	45	0	3	0	26	6	451	0		
	Inner	45	0	0	6	18	0	289	0		
„ „ 2 (South) .	Outer	45	0	3	0	26	6	454	0		
	Inner	32	10	0	6	18	0	286	0		
										1,480	0
Prince's		45	0	5	9	28	2	..		277	4
Canning, No. 1 (North) .		35	9	Above. 1	8½	23	3	436	0		
„ „ 2 (South) .		35	9	Below. 0	0½	23	3½	482	0		
										918	0
Queen's, No. 1 (East) . .		42	0	1	8½	27	7¾	465	0		
„ „ 2 (West) . .		70	0	3	6	27	5	467	0		
										932	0
Brunswick, No. 1 (East) .		42	0	2	6	26	6	460	0		
„ „ 2 (West) .		42	0	2	6	26	6	462	0		
										922	0
Herculaneum, No. 1 (West)		60	0	4	0	26	0	758	6		
„ „ 2 (Middle)		60	0	4	0	26	0	753	0		
„ „ 3 (East).		60	0	4	0	26	0	768	0		
										2,279	6
Total length of floor of the Liverpool Graving-Docks . . .										12,489	10

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[1] The depth of water over the sills of the Sandon Graving-Docks can be increased to any desired extent by pumping into the Sandon Dock from the river so as to allow of deep-draughted vessels entering on low neap-tides.

BIRKENHEAD GRAVING-DOCKS.

Name and Position.	Width of Entrance. Ft.	Width of Entrance. Ins.	Sill below Datum. Ft.	Sill below Datum. Ins.	Coping at Hollow Quoins above Datum. Ft.	Coping at Hollow Quoins above Datum. Ins.	Length of Floor. Ft.	Length of Floor. Ins.	Total Length of Floor. Ft.	Total Length of Floor. Ins.
West Float, No. 1 (East) . . .	60	0	4	9	25	0	930	0		
„ „ 2 (Middle) . .	48	4	7	9	25	0	750	0		
„ „ 3 (West) . . .	85	0	7	9	25	0	750	0		
									2,430	0
Total length of floor of the Birkenhead Graving-Docks . .									2,430	0
„ „ „ Liverpool „ „									12,489	10
Total									14,919	10

LIVERPOOL GRIDIRONS.

Site.	Breadth of Gridiron. Ft.	Breadth of Gridiron. Ins.	Length. Ft.	Length. Ins.
Clarence Graving-Dock Basin . . . . The blocks are laid 2 feet 2 inches below the datum at the south end of the gridiron, and 3 inches below at the north end.	25	6	313	6
King's Pier . . . . The blocks are laid at the level of the datum.	26	0	509	0
Total length of the Liverpool Gridirons			822	6

LANDING STAGES.

Liverpool.—Stage 2,063 feet long by 80 feet wide, has seven bridges connecting it with the shore, besides a floating bridge 550 feet in length, and 35 feet in width, by means of which an easy incline for carriage traffic is maintained at all times of the tide. The stage was destroyed by fire 28th July, 1874, and afterwards restored.

Birkenhead.—Woodside Stage, 800 feet long by 80 feet wide, has two bridges connecting it with the shore, besides a floating bridge, similar to that at the Liverpool Stage, 678 feet in length by 30 feet in width.

Note.—The southern end of the Woodside Stage, for a length of 300 feet, together with the southern bridge, is appropriated to the Corporation of Birkenhead.

Wallasey Stage, 350 feet long, 70 feet wide, connected with the shore by two bridges and platforms on iron piers.

AREA of the DOCK ESTATE.

	Acres.
Liverpool	1,083
Birkenhead	506
	1,589

[DISCUSSION.

Discussion.

Sir John Coode. Sir JOHN COODE, K.C.M.G., President, observed that both from a commercial and from an engineering standpoint, the Paper was full of interest and of instruction. The Author was to be congratulated upon the project of 1871; it seemed that he had created a revolution in the Liverpool dock system, and one which had fully met the requirements of modern trade. The wisdom of that project had been justified by experience. With regard to the Canada Basin, the direction of the entrance, and the sluicing arrangements from the Langton and Canada basins, were admirable. The mode of working the sluices, and the protection of the outlet of the pipes by means of greenheart caps from the admission of mud and sand, had met the case thoroughly, and the proof that it had done so was to be found in the admirable working of the past eight years. The erection of cranes on the front walls and ridges of the warehouses was a new departure, and seemed likely to be followed by engineers in the future, owing to the efficient way in which the cranes performed the duty required of them.

Sir Robert Rawlinson. Sir ROBERT RAWLINSON, K.C.B., Vice President, said he entered Mr. Hartley's office in 1831, and was principal draughtsman for the last two years of his service. He considered Mr. Hartley one of the greatest masonry engineers that the world had produced, and knew of no works of the same stamp of character as the range of docks which he had designed and carried out. Sir Robert Rawlinson made the first connected plan of that range of docks when he was in Mr. Hartley's employ. He recollected the original "Old Dock," and also saw it filled up by the foundations for the custom-house. In fact he worked as a mason on those foundations when the "Old Dock" was being filled up. He knew the difficulty there was in providing sluicing power to keep the entrances of the docks clear. He also remembered the proposals as to the great docks at Wallasey Pool. The engineer contemplated a sill, 29 feet below the Old Dock Sill; but that had been abandoned; he, however, heard the evidence given in its favour in a Committee Room of the House. He would ask the Author what had been the cost per cubic yard of the class of work carried out, and why he had used Portland cement in place of Halkin mountain mortar such as Mr. Hartley used? He was satisfied that without the extensive flushing arrangement

Sir Robert Rawlinson.

adopted by the Author, great difficulty would have been experienced in maintaining the sluices at the depth at which they had been put on the north shore, for it was a lee shore, and the deposit from the Pluckington Bank was very rapid. In order to explain the extraordinary changes in the Pluckington Bank, he might state that at the George's Basin, which had been abolished, he had known the old small floating stage at 6 o'clock on one night hard aground on a bank, where at 6 o'clock on the following evening there was a depth of 15 feet of water; the scour upon the tail of the bank having washed the sand away to that extent. He was satisfied the Author had an arduous, difficult, and somewhat dangerous piece of work in dealing with the George's Dock, because the basin itself stood upon piles. Upon one occasion of sluicing, the current was allowed to flow against the southern projection of the basin entrance, and it washed the whole of the sand and silt away from the pile heads. An extraordinary occurrence happened on the north wall of the basin, where there was a vertical sluicing culvert about 5 feet high and 3 feet wide, connected with the Prince's Dock on the north side. There had been a tide of 21 feet, and the sluices into the George's Basin had become choked. The water came into communication with the horizontal culvert, and when the tide went down, the extra pressure, which could not be more than that due to 4 or 5 feet, split the wall—a very old one—from bottom to top. The Author had, however, provided against that risk in his arrangement of sluicing pipes. There was a curious circumstance with regard to that form of sluice. At the recommendation of Mr. Hartley he became engineer to the Bridgewater Trust, and within a month a similar accident happened to the old wall of the Runcorn Canal Dock, in which there was a sluice similar to the George's Dock sluice, the old wall being split. In such cases he advocated flat in preference to vertical sluices, unless cast-iron pipes were used.

Mr. Hayter.

Mr. Harrison Hayter, Vice President, observed that the Tables appended to the Paper would be of service to those engaged in dock practice. He would make a few remarks as to the masonry, which was of a somewhat peculiar kind, little known anywhere but at the Liverpool docks. The Author had shown the type he referred to in *Fig. 1*, p. 20, which accurately delineated the chief characteristics. Mr. Hayter had examined this masonry not long ago; it consisted of a rubble facework of granite, backed with concrete. The face-stones were of two kinds, about one-half consisting of small stones, and the rest of larger stones. All, however, were shallower on the bed than usual, the larger stones being from

Mr. Hayter. 1 foot to 2 feet, or at the outside 2 feet 6 inches, and the smaller only about 6 inches or 7 inches. Each stone, whether large or small, was drafted on the edges of the face, the rest of the stone being punched with a steel punch. But the punched work never projected beyond the drafted edges, so that ships, if in contact with the wall, would meet with a smooth surface. In selecting this kind of masonry, no doubt regard was had to the quarries in the south of Scotland belonging to the Board, from which the stone was obtained. This stone, although of excellent quality, was stated to be difficult to get in square blocks, and its beds were dislocated, producing probably stones of sizes smaller than usual. Masonry of the kind he referred to required very good mortar. That used generally was made from Halkin lime, which was a lias lime, much in vogue before the use of Portland cement became general. Notwithstanding the not altogether favourable conditions, the kind of masonry seemed to have answered. Indeed, it might be expected that the Author would adopt no bond, and use no material, unless he were sure that good work would result. Sir Robert Rawlinson had alluded to the masonry, but in general rather than specific terms. It would have been well had he said something more thereon, as no one had a more practical acquaintance with the subject than he possessed. But the object Mr. Hayter had more particularly in view was to direct attention to the 30-cwt. roof-cranes in connection with the two-story or double sheds placed near the quay-edge, that was to say, 8 feet 6 inches therefrom (Plate 3). He did not think the Author had sufficiently stated the advantages of cranes running on the roof of the sheds, and of the general arrangement. The reason for this was probably because his son, Mr. A. G. Lyster, M. Inst. C.E., was the inventor of the cranes, and they were passed over in the Paper with only a few words. Mr. Hayter had examined the cranes very carefully, with the view of adopting them and a like arrangement elsewhere. The advantages of the arrangement were great. In the first place, owing to the proximity of the wall of the shed to the dock, it could be founded on the dock wall itself, and thus a good foundation be ensured for the shed wall which supported the greater part of the weight of the crane. This was the more important because generally, at the back of dock walls, there was made ground, and foundations had often to be carried down to a considerable depth. A second advantage was that the crane was in a lofty position, enabling the person working it to see into the hold of the ship, and to direct the men, and enabling him also to lower the lifting chain of the crane directly over the load to be raised, Mr. Hayter.

thereby saving trouble and economising time. Owing to the lofty position, also, the crane could be kept clear of the rigging of the ships, and could run to and fro clear of mooring-posts and moorings. A third advantage arose from the circumstance that there were no cranes running and swinging their loads on the quay between the shed wall and the water's edge, so that the men conveying the goods from the ship to the ground floor of the shed could work uninterruptedly and in safety. And a fourth advantage was some economy in construction, in that there was a solid foundation for the crane roads, one set of wheels running on the shed wall and the other on the ridge of the roof. Beyond strengthening the top ridge-piece, little or no alteration was required in the roofs. As regarded the distribution of weight, there was a pressure of from 12 to 14 tons on each of the wheels on the shed wall, and about 2 tons on each of the wheels on the ridge, these being the highest pressures when the crane was fully loaded. The maximum upward pull at the ridge was 3½ tons, counteracted by ballast. Any jerk which might increase the upward pull was provided against by clipping the cranes to the rails with the usual clips. At the level of the upper floor there was an outside gangway, about 4 feet wide, serving as standing-room, to enable the load to be caught hold of and lowered. Evidently these cranes were applicable for single sheds, but they were more especially so for double sheds. In the first place, double the floor-area was obtained on the same piece of land, a desirable point where land was costly, as it so often was at dock quays. Then the lower floor could be used for the outward cargo, and the upper floor for the inward cargo; and, this being so, when a portion of the ship was cleared, the loading could be begun, so that the two operations of unloading and loading could, to some extent, go on simultaneously. The inward goods, also, being on the upper floor, could be readily lowered into wagons or carts for removal by simple appliances. From his experience in the construction of docks, he had found that, as a rule, the best position of sheds was near the quay edge, leaving a space, say from 7 to 10 feet, between the shed and the water. Probably the more common practice was to place two lines of rails between the shed, or warehouse, and the dock, and this might, under certain circumstances, be necessary. But it was impossible to take away goods from a ship without interruption if they were all to be unloaded into railway wagons. The space was too circumscribed, shunting was likely to be hindered, and it was difficult to ensure a constant uninterrupted supply of railway wagons. All goods, of course, were not admissible into sheds, but

Mr. Hayter. where they were, the best way to deal with them, as a rule, was at once to transfer them from the ship into the shed. In this way the ship could be released within the shortest possible time, and the goods in the shed be distributed with the requisite despatch. Of course, if the goods remained too long in the sheds, demurrage was charged. The result of the arrangement adopted at Liverpool was somewhat remarkable. He had been told by Mr. A. G. Lyster that upwards of 800 tons of goods per lineal yard of quay per annum had been passed through the double sheds. In ascertaining the capability of a dock, he had been in the habit of assuming that 350, or at the most 400 tons of goods per lineal yard of quay per annum could be dealt with; and this was the normal rate of working at a dock constructed by his firm not long ago in London, where the appliances were modern, the whole dock having a hydraulic installation, and where the provision of quay and shed was good. It was certainly always safe to assume this rate of working, and if it could be increased, as at Liverpool, the capability of the dock for certain kinds of goods would, of course, be proportionately increased. This was of great importance to owners of dock property. He was glad to have the opportunity of directing the attention of the Institution to this particular subject, because he believed hitherto no attempt had been made to lay down rules to enable engineers or others to say beforehand what work could be done in docks, except it might be in those the chief traffic of which was coals or minerals loaded from staiths or drops.

Mr. Giles. Mr. A. Giles, M.P., said it was not the privilege of every engineer to represent 6 miles of docks, with a capital expenditure of about £18,000,000, and a gross revenue of over £1,000,000; and the Author of the Paper, who had had the control of that vast establishment for the last thirty years, deserved the warmest thanks for the details he had given of the construction of those works. The Author mentioned the difficulties he had encountered, and the remedies he had adopted to overcome them. One of the foremost of those difficulties was that whereas it was prophesied, some time ago, that the sills of the Liverpool Docks could not be carried below low-water, or even anything like down to low-water, the Author had succeeded, by means of sluicing, in keeping the sills 2 feet below low-water at the lowest spring-tide, and 10 feet below the Old Dock Sill. Having been on the pier-heads of the Canada Basin upon several occasions, and having watched vessels coming in at high-water, he could only say that the system adopted there was one peculiarly adapted to the difficulties of

Liverpool. With the tide running up 6 or 7 knots an hour it was quite impossible for a vessel coming in to shoot the entrance. Vessels therefore went above the entrance, turned round and faced the up-current, and went in against the stream; and for that purpose the Canada Dock entrance was well suited. At the same time, when vessels entered in that way, and the docks were not large enough for the larger class of vessels to turn round, he understood that they frequently went out stern foremost. He did not know that that was a great objection; but still, it was better to go forwards than backwards. The Author had mentioned the style of masonry he had adopted for the dock walls, and it was impossible for anybody to examine those splendid works, the solidity of the masonry, and the way in which it was put together, without feeling that it was right. Where stone was cheap, as it was in the neighbourhood of Liverpool, he thought uncoursed masonry was better than concrete, and he doubted whether that system of masonry was much dearer than concrete. The greater part of the Liverpool Docks was designed when railway communication was almost unknown; but it appeared to him that if the more recent docks had been constructed so as to get better railway communication round them, it would have been more consistent with the ideas of the present day. The fact was that rapidity of motion was absolutely necessary in order to make large steamers, costing £250,000 or £300,000 each, a commercial success. Shipowners could not afford to let so costly a plant lie idle many days; they wanted to get the vessel into harbour quickly, discharge it, re-load it, and turn it round. He had himself seen large vessels in the Liverpool Docks being unloaded without the help of the railway system—loading into carts—and he thought it was not quite consistent with the practice of most ports. He believed that Liverpool was more of an emporium than a port where goods were landed and shipped for rapid transit into the interior. There were many up-town warehouses, and the owners of those warehouses were quite content to get their goods delivered by carts; at the same time, whenever a new dock was constructed nowadays, one of the first things required was that there should be railway communication round the quays. He had sketched out a dock he was just completing, which was something different to the fashion of the old retangular dock. It was in the shape of a diamond, with railway communication alongside the quays, and round the sheds, without the use of a turntable or sharp curves. Moreover, any vessel could berth herself without delay, and almost without the use of warps. The Mr. Giles.

Mr. Giles. want of railway communication was, he thought, a blot in the plan of the Liverpool Docks. Whether it was possible to get railway communication round the docks he was not sure; but, looking at the plan, he did not consider the railway communication quite sufficient. With regard to the estuary, he could not subscribe to the statement that the meandering qualities of the River Mersey, above the narrows were the cause of keeping that estuary open. It might be so; but he thought that, with the tide running into the estuary at the rate of 6 or 7 miles an hour, and out again at the same rate, if the channels of the Mersey and the Weaver were carried straight through the estuary, there would be no more chance of that estuary silting up than there was at present. He had seen it stated that the Dock Board was going to try to improve the bar, and all engineers who had had anything to do with the Mersey must have felt that the bar was the sticking point of the port. Voyages across the Atlantic were reckoned by minutes; but if a vessel arrived off the bar of the Mersey on a falling tide, it could not go in, because at the bar there was only 10 feet depth of water, while the craft drew 23, 24, or perhaps 25 feet. It was a matter of astonishment to many people that the Mersey Docks and Harbour Board, having been able to spend nearly 18 millions in making the magnificent system of docks, not only along the eastern shore, but also at Birkenhead on the western shore, had not attempted before now to try and improve the bar. It had been said that the experiment of dredging was to be tried. In his opinion it would be just as well to throw the money into the river at once, for he did not believe that any dredging of the bar would keep it open. The Author had said that it was a matter of considerable physical and financial difficulty. Mr. Giles admitted that, but he did not think it need be such a financial difficulty as some people imagined. He thought a means could be devised of forming a guide for the stream, a training-wall, which the ebb and the flood could hug on the concave side; and he believed this would scour the bar out to a greater depth. He hoped that the Mersey Docks and Harbour Board would bear these remarks in mind, for he was quite sure something better than dredging ought to be attempted.

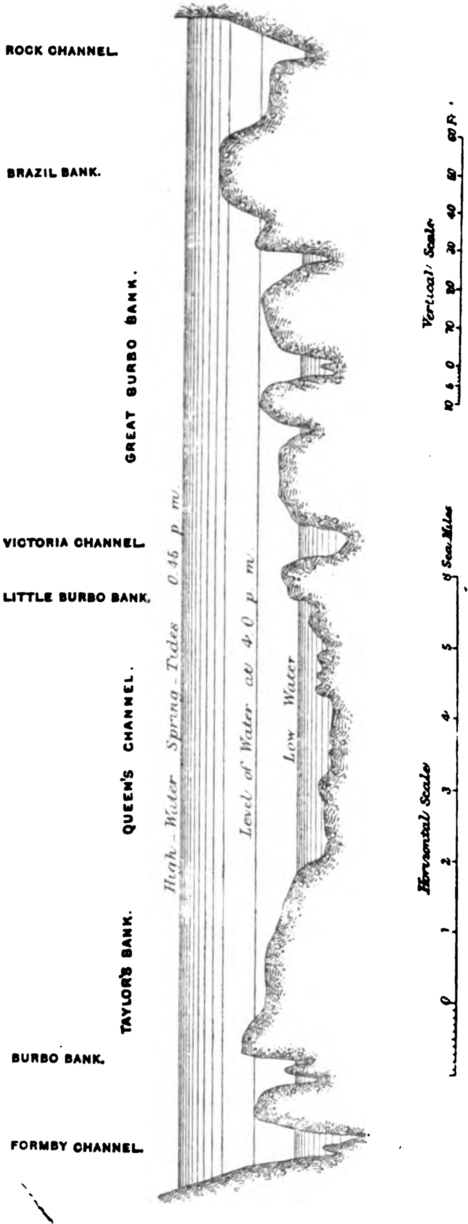
Mr. Law. Mr. Henry Law observed that the port of Liverpool was, no doubt, in many respects unique, presenting features of great interest to the hydraulic engineer. Its external situation in the corner of two long shores meeting at a right-angle, with a copious supply of sand, was peculiar. There could be no doubt that but for the very large volume of water passing in and out every tide, it

Mr. Law.

would long since have become a solid beach, as the Author had suggested. It was therefore of the utmost importance that nothing should be done which should in any way tend to lessen the quantity of water passing in daily. Compared with the tidal flow, the land water was extremely small, although he agreed with many hydraulic authorities that even that small quantity of drainage water, by finding its way through the large sandy inner estuary, did prevent it from becoming gradually silted up. Those who desired to pursue the question and the principles involved might read the evidence given, especially in the third Session in which the Manchester Ship-Canal Bill was brought forward, when the matter was fully discussed, and the position which he had mentioned was sustained. Bearing in mind the importance that no extraction of tidal water should take place, blame had occasionally been put upon those who designed the docks for having reclaimed them from the shore of the river, although they did not extend beyond the low-water line. But on further consideration he thought that a different opinion would be formed; and that it would be seen that by building the walls in their present position, by converting that which was a very irregular and unequally wide channel, and with rough shores, into a channel approximating to the *vena contracta*, theoretically a larger volume of water would be able to pass up; and such had actually been the case. A comparison, of the tidal observations taken in 1844, with more recent ones, certainly led to the conclusion that the range of tide had been appreciably increased; and when it was remembered that every foot of tidal range that could be obtained in the inner estuary meant an addition of no less than 36 million cubic yards of tidal water every tide, or one-seventeenth of the average tidal flow, it would be seen how important it was not to do anything which would diminish that tidal flow. But irrespective of the great benefit arising from the formation of what might be called the established regime in the lower part of the river, or from inducing the tidal water to flow up, the mere abstraction of water under the condition in which it was abstracted by the construction of the docks was a matter of small importance. *Fig.* 2 was a developed section of the highest ridge of the sand-banks, starting from Formby Point, passing over the bar and through the Rock Channel near New Brighton. The section showed the remains of what had been known as the New Channel, but it had disappeared, also the remains of the Victoria Channel, named after the Queen when she was Princess Victoria; and then came the Queen's Channel, which was the existing entrance to the port. The bar was indicated by a red

Mr. Law.

Fig. 2.



and black buoy. It was evident on looking at the section that at high-water the water passed over such a large area that it could produce scarcely any useful effect in scouring the bar—first, because the greater part of it did not pass there; and secondly, because what passed did so at a very low velocity. Upon the model before him, by making a horizontal section at 5 fathoms below the Old Dock Sill, he was enabled to show a similar ridge, only in its natural form, to that shown upon the developed section, and it would be seen that at low-water the area through which the water could flow was very small and concentrated. It was only one-tenth of what it was at high-water, and, therefore, any abstraction of water from the upper part of the estuary, which would otherwise have arrived at the bar towards low-water, must be of a very serious character. He would remove a sandbank in the model and thus reveal the extent exposed at high water over which the water flowed. With regard to the inner estuary, he would only refer to the way in which the channel after passing the Narrows bifurcated, one channel passing up towards Garston, and the other towards Eastham. The plan, which was Captain Graham Hill's most recent survey, showed how Dingle Point, as the Author had stated, threw the ebb stream across, and was really the cause of the Pluckington Bank, which gave so much trouble. He had also shown two sections, both starting from a point opposite the Coburg Dock; one section taken on the line of the deepest water up to Garston, and the other being a section taken along the deepest water up to Eastham. On the following Table were exhibited the Mr. Law.

SECTIONAL AREAS of WATERWAY over the HIGHEST RIDGE of SANDBANKS which EXTEND ACROSS the BAY and FORM the ENTRANCE to the PORT OF LIVERPOOL.

Time.	Height referred to Old Dock Sill.	Sectional Area in Square Yards.	Proportional Area.
High-water spring-tides . . .	+20·00	290,500	10·21
Six hours before low-water . .	+19·32	267,600	9·41
Five „ „ „ . .	+15·37	236,080	8·30
Four „ „ „ . .	+ 9·09	169,700	6·00
Three „ „ „ . .	+ 2·36	103,250	3·63
Two „ „ „ . .	− 2·64	58,485	2·06
One „ „ „ . .	− 7·45	36,615	1·28
Low-water spring-tides . . .	− 9·33	28,444	1·00

areas in square yards of the channel over the ridge of sand at one, two, three, four, five, and six hours before low-water, and it would be seen that taking low-water as unit, the high-water area at a 21 feet tide at St. George's pier was ten and a quarter times as great.

Mr. Kinipple. Mr. W. R. KINIPPLE said that cranes of a precisely similar design to those referred to in the Paper had been proposed by himself several times over, as far back as 1873–74, and reported upon, to the Greenock Harbour Trustees on the 20th of June, 1882, in connection with some sloping-roofed sheds on jetties proposed to be erected in the Albert Harbour, and cranes of similar design to travel on the roofs had been proposed for the extensive range of sheds and warehouses at the James Watt Dock. He agreed with what Mr. Hayter had said with respect to those cranes, for in his opinion they embodied all the best features of the best cranes extant. In the James Watt Dock at Greenock he had something very similar to them now at work, except that one leg of each crane travelled on the dock coping and the other leg on the upper platform or second quay. At this dock unfortunately there was not sufficient trade at present of the class anticipated to keep the cranes fully employed. There were sheds with two stories. One he called the import quay and

Mr. Kinipple. the other the export quay. On the diagram showing the section of the wall below the crane, Plate 3, he noticed a rocky bottom. In the present day, when vessels had very flat floors or square bilges, it did appear to him that, unless the dock was very deep and there was plenty of water under the vessel, the bilge of the ship would most likely be indented if it settled down on the rock, especially if the rock was not plane. He had done a great deal of facing work, but not in the way mentioned in the Paper. It was simply brickwork in Portland cement, or Portland cement rubble concrete veneered or faced with granite. With reference to the angle at which the entrance to the Canada Basin was placed, he quite agreed with Mr. Giles that in a river where there was such a strong current as that at Liverpool the direction chosen by the Author was the best. On returning from Canada the steamer on which he was on board went into that dock. After crossing the bar he wondered how it would be possible to get round quickly and into the dock, knowing that the gates were to be closed in about an hour and a half. But the operation was skilfully and easily performed. The Hornby Dock wall and also the Langton Dock wall were founded on boulder-clay, which for trustworthiness he regarded as next to rock. He had spent a great deal of money in docks, having built some 50,000 or 60,000 lineal feet of piers, quays and walls; but he had never had enough money to build walls of the strength of those described in the Paper, whose bases were exactly half their heights. He should like to ask the Author why those walls had been made of such enormous strength, and what was their factor of safety. With regard to the Canada Basin, he thought the system of flushing there was very good but very costly. He had been engaged during the last eight or ten years in training the navigable channel of the Burry inlet in South Wales. There he found that by the aid of a single training-bank well up the river he could influence the channel in the lower reaches, some 3 or 4 miles away from the works; in fact, he had shifted for its full width a channel of 600 yards in about two months. No one was more astonished than himself. He went to look at the channel, and in its place discovered the fairway buoys high and dry. This extensive alteration of position was simply due to a moderate sized training-bank, 10 or 15 feet high and about 3 miles long. He thought it would be well to train the channel of the Mersey from the south on towards the Pluckington Bank on the Liverpool shore. With regard to the 6 miles of narrows, there were very few channels in the world of such depth and width in front of so important a town

Mr. Kinipple.

as Liverpool. No doubt that channel had made Liverpool. But what had become of the public spirit in Liverpool in delaying so long in attempting to deal with the bar? That bar during his lifetime had been spoken of and condemned by most men. The model exhibited by Mr. Shelford, distorted vertically to a large scale, was a very excellent one, and enabled engineers to think seriously and readily what was best to be done to obtain deep water. Any attempt to remove the bar with sand dredgers would, he thought, simply involve an annual outlay of many thousands of pounds. Some millions of tons at least must be removed before it would be possible to get 4 or 5 feet greater depth of water; and having done that it would simply mean a return sooner or later of the former evil, and then it would be necessary to repeat the operation. In his opinion the proper course to pursue was to train first and then remove by dredging what could not be scoured away. The estuary outside New Brighton indicated that immediately past that place there was a great dissipation of the ebb current, especially during its last half. It would have been better if the Author, in years gone by, instead of throwing the spare rock and stiff boulder-clay from the dock extension works into the sea some miles away, had used these materials in laying down one training-bank, say on the western side of the channel way, along a portion of the general line of the deep-water channel, extended in a north-westerly to northerly direction as need required; and the other at ½ mile therefrom on the eastern side at the mouth. He had dealt with six or seven somewhat smaller cases, and he had experienced no trouble along the entire line of the channel, except for a short distance, or length, inside of and at the crown of the bar. On the Clyde he had used rubble, and boulder-clay which was called "till" in Scotland. That till, when tipped into the Clyde, had become softened almost to the consistency of thick pea-soup, and took a flat slope. After six months it had hardened to such an extent that he had found sea-weed growing on it, and it was impossible to tell by looking at it from the pier whether it was rock or clay. He thought, if ever training-banks were laid down, it would be better in the first instance not to deposit too much rubble or big stones, but to try tentatively what the effect of two very slight training-banks would be, laid about ½ mile apart, the western one commencing at a considerable distance inside the bar, and gradually extending by a curve in a northerly direction up to and across the site of the bar as the sand was scoured away, and the eastern one with a slightly concave face to windward extending somewhat seaward of the western bank. His impression was that instead of spending

Mr. Kinipple. thousands of pounds on suction dredgers and plant of that kind, it would be far better to send down so much suitable waste spoil, drop it from some of the hopper-barges, and so practically do the work gratis and wait. He was sure work of that class would not interfere with the shipping, because, to commence with, the tops of the banks need not be higher than 15 feet under low-water mark. The banks could afterwards be gradually raised until a scoured-out depth of about 20 feet over the bar had been obtained. In his opinion this was well worth a trial, and he sincerely believed that the mode he had suggested would be effective, and the readiest, cheapest and best way to go about the work.

Mr. Shelford. Mr. W. SHELFORD remarked that the special characteristics of the Mersey had been referred to by the Author, and had been discussed pretty freely for some years elsewhere. He believed that this had given rise to a new departure in hydraulic engineering, as a most ingenious system of working models of estuaries had now been brought into use, which was conceived and carried out by Professor Osborne Reynolds. The subject had been taken up by a Committee of the British Association who had worked at it for the last two years, and from the report of that Committee, made at the Newcastle meeting last year, there could be no doubt that very valuable information and useful results would be obtained. The working models automatically represented the currents and sands in the estuary itself, so that by observing the model, the main points which affected the tidal regime could be studied. For five-and-twenty years past he had himself been in the habit of occasionally making models of the beds of estuaries, by taking the latest edition of the Admiralty charts and plotting all the soundings to a large vertical scale, say 15 to 20 feet to the inch. In that way he found that the effect of every sounding could be shown on the model, and a great many lessons might be learnt as to the condition of the estuary from the representation thus obtained of the bed of the sea. He had made such a model of the Mersey estuary, or rather of Liverpool Bay, which was the lower estuary of the Mersey. The plane of the model, which he exhibited, was that of the Admiralty chart. The dark brown indicated all above high-water, the light brown all between high-water and low-water, and the blue all that was below low-water at spring-tides. The model would bear careful study, and would be found highly instructive in many matters of detail. It would be seen that the very marked main channel coming out from Liverpool was an important channel below low-water, and that the channel to the north of it, known as "Formby Deeps," or The Old North

Channel, was practically silted up; also that the whole of that portion of the bottom of the sea was covered with sand and might be considered to be comparatively stable, so that there was little fear of the main channel ever taking that course again. He would also draw attention to the extraordinary character of the bar. It was a ridge of sand so marked that it looked almost like a railway tip. The ebb-tide coming from the Mersey carried its burden of suspended matter, and on reaching still water deposited its load. That had taken place and still took place, he believed, to the north, so that there would appear to be a tendency on the part of the ebb-tide to deposit its load to the north. On the south side of the main channel there was a totally different state of things; the deepest water lay to the west of the Bar Lightship; and the flood-tide came up through this deep, and made its way south-eastwards to the Mersey. The Rock Channel, well-known for navigation purposes, was chiefly caused by the flood-tide coming along the coast. Everywhere there was a tendency on the part of the flood-tide to force its way through the sands into the Mersey. The chief effect of the model was to show that the tendency on the part of the ebb-tide was to deposit its load to the north, and that there was a tendency on the part of the flood-tide to outflank the main channel and force its way into it. That was the state of things at the present time in the Mersey, and the recorded facts confirmed that view. The Victoria Channel was for years the main channel for navigation purposes. It was formed when the flood-tide out-flanked the bar in the Queen's Channel and broke into the main channel, producing a greater depth of water. This varied very much during many years, the greatest depth being in 1861, when it was 17 feet. Then the Queen's Channel recovered itself, and the depth of the water upon the bar became fixed, about six years before 1884, steadily at 9 feet. Towards the end of 1884 a remarkable thing occurred. Again the operation came into action, the flood-tide broke in by slightly outflanking the bar, and lowered it 1 foot, and the Mersey authorities recognised the change, and shifted the navigation so as to get 10 feet over the bar. The model showed that the flood-tide was trying to re-open the Victoria Channel. The Author had stated in the Paper: "It is a universally accepted opinion, by competent authorities, that any extensive exclusion of tidal water from the estuary must injuriously affect the sea-channels, and finally destroy the port of Liverpool." That was a pregnant, not to say somewhat alarming, statement. The Mersey estuary was, in his opinion, clearly divided into two parts. Mr. Shelford.

Mr. Shelford. Liverpool and Birkenhead were in the centre of the estuary; above them there was the Upper Mersey, and below them was Liverpool Bay, which being chiefly under water was not often noticed, in fact all the information in the Institution on the subject of the Mersey was confined to the Upper Mersey, very little having been said about the Bay. The Author had given the quantity of tidal water in the Upper Mersey as 710,000,000 cubic yards, and had omitted altogether to give the quantity of tidal water between New Brighton and the bar. It was obvious that in considering the bar the water which passed over it, and ran 11 miles before it reached Liverpool must not be ignored. He had gone into the question closely, and had had the opportunity of using the surveys of the Mersey Docks and Harbour Board or the Conservators of the Mersey for the purpose of making his calculations, and he found that the figures given by Mr. Law agreed generally with his own, as shown in the annexed Table. The first column showed the times, the second the quantities discharged from the estuary, the third the quantities discharged from the bay, and the fourth the total quantity discharged. The last column showed the velocities. It would be seen that from the time of high-water to 4 o'clock, namely, before the banks were uncovered, two-thirds of the volume of the tidal water had ebbed away at a velocity varying from 0·4 to 1·3 knot per hour. After the banks were uncovered the main channel came into operation as an ordinary channel upon dry land; and so complete was the analogy that the sectional area had proved remarkably uniform, as long as the width did not exceed 6,000 feet, after which the

31 Feet Tide.	Quantity Discharged.			Mean Sectional Area of Discharge.	Mean Velocity.
	From Estuary.	From Bay.	Total.		
P.M.	Million Cubic Yards.			Square Feet.	Knots per Hour.
H.W. 12.15 to 1.45	139	178	317	2,494,135	0·4
1.45 „ 3.0	248	189	437	1,736,000	0·9
3.0 „ 4.0	153	152	305	1,031,000	1·3
4.0 „ 5.0	129	104	233	573,500	1·8
5.0 „ 6.0	71	91	162	323,000	2·2
6.0 „ 6.45 L.W.	48	19	67	213,000	1·9
Totals . . .	788	733	1,521		

Mr. Shelford.

conditions became less stable. Some of the water, it was true, leaked out through the side channels, but the bulk went over the bar. The period of greatest mean velocity (2·2 knots per hour) was reached between 5 and 6 o'clock, low-water being at 6.45. That was not the velocity on the bar, but the mean of all the channels open at that time, and indicated on the section which Mr. Law had shown. He would sum up by pointing out that between 5 and 6 o'clock, the period of maximum velocity, 162,000,000 cubic yards only were discharged. That represented only about $\frac{1}{10}$th of the whole quantity discharged from the estuary, and of the 162,000,000 cubic yards, 91,000,000 came from the lower estuary, and 71,000,000 from the upper. Thus the quantity of water which was most important, as determining the navigable conditions of the Mersey, was that below the Rock Lighthouse, and inside the bar, which had hitherto been ignored. That was material, because it seemed to show that the quantity of tidal water passing down a river was not of so great importance as the disposition of it. If by any means a smaller volume of tidal water could be thrown into the upper part of the estuary, even though it sacrificed part of the quantity in the estuary, so as to produce a greater velocity between 5 and 6 o'clock in the lower channel, it would be more beneficial than the present great quantity which was entirely uncontrolled. In saying that he advanced nothing new, he believed he was safe in asserting that there were veteran hydraulic engineers who had founded their reputations upon it. The point which really constituted a danger to the Port of Liverpool was the want of any attempt to control the great mass of water flowing over the bar and through the sands in the bay.

Mr. Vernon-Harcourt.

Mr. L. F. VERNON-HARCOURT said that he thought there was one mistake in the Paper. He believed there was an older dock in London than there was at Liverpool. As far as he could make out, searching among different records, he found some years ago that, at the Surrey Commercial Docks, there was what was known formerly as the Howland Great Wet Dock, which was said to have been constructed in 1660, now called the Greenland Dock. It might be in the knowledge of some engineers that soon after a Paper of his on the River Seine was read before the Institution[1] in 1886, he began, on account of the great difficulties that there seemed to be in getting any reliable idea of what training-walls would produce in an estuary like the Seine, to institute a long series of

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxiv., p. 210.

Mr. Vernon-Harcourt.

experiments, the results of which were published last year.[1] He found, first, that he was able, in taking the whole of the tidal Seine, to get fairly approximately, as Professor Reynolds had done for the inner part of the Mersey estuary, something like the state of the channels as they existed at one time on the Seine. He then introduced the existing training-walls of the Seine in the model, and obtained approximately the results that now existed. Then he introduced various schemes with different results, exhibited in the plates illustrating his Paper read before the Royal Society in February, 1889. At the beginning of last year, having completed his experiments on the Seine, he thought it desirable to turn his attention to the estuary of the Mersey. There were two points which were necessary to try and elucidate. One was what the effect of the training-walls in the upper estuary would be; and the other, whether it was possible to carry out training-works with a prospect of improving the bar. He began those experiments last year, and they had been lately completed. The results obtained were fully described and illustrated in a Paper read before the Royal Society on the 30th of January, 1890. He first made a small model of the Mersey, and did not merely confine himself to the inner estuary, because that would not have shown what the influence of training-walls might be upon the outer estuary, by which he meant the estuary beyond New Brighton. He therefore made a working model on a small scale of the whole of the estuary of the Mersey, going nearly up to Warrington, and taking it beyond the bar. He then obtained, by working the model, the shifting channels in the upper estuary; and he also got the Rock Channel, and the small in-shore channel near Formby Point. So far, because it was not possible to reproduce winds and waves in a model, the results were approximately like the actual results seen in nature. He now, with considerable interest, put training-walls in the upper estuary resembling the scheme that was proposed for the Manchester Ship-Canal in 1884. Then the model was worked for some time; and a change very soon became apparent. The upper estuary began to silt up, and the channel below New Brighton began also to silt up. There was a very distinct shallowing of that channel on account of the silting up of the upper estuary. Therefore it seemed, as far as could be judged by experiments, that the results of putting any training-walls in the upper estuary of the Mersey were what some engineers

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[1] Proceedings of the Royal Society of London, vol. xlv., p. 504, and plates 2 to 4.

Mr. Vernon-Harcourt

said would be the case—that the channels below Liverpool would be injured. He next went on to see what could be done for the improvement of the bar, because it did not seem to follow that because training-walls were bad in the upper estuary, as he long ago believed they would be,[1] they would be bad in the lower estuary. The great point, he thought, was to arrange the training-walls so that they should not interfere with the tidal flow into the upper estuary of the Mersey. He did not see what harm such training-walls could do to the bar. He therefore put training-walls, made of strips of tin, into the model, taking them along the sides of the present channel to a certain distance, and causing them to diverge slightly so as to prevent any obstruction of the tidal flow into the narrows. Having worked the model with this arrangement for some time, the sandbank between the bar channel and the inner Formby Channel was gradually washed away, and he got a considerably deeper channel than the existing bar channel towards Formby Point to the north. He did not feel satisfied that that was absolutely the best way of dealing with the case, but it gave the assurance that training-walls in the outer estuary of the Mersey would produce a different effect from what they would in the inner estuary. Instead of leaving sandbanks in front of the outlet of the trained channel, he removed them to the depth of the bar; he then worked the model again, and got a much straighter channel, in the direction of the present channel. He was also able to get a decidedly deeper channel than the bar channel by means of those training-walls, and the removal of the sandbank, which might be regarded as dredging. From those experiments, reproducing in miniature the general results of the ebb and flow of the tide, but not any action of the winds and waves, it appeared that it would be possible by means of training-walls, carried out if necessary on both sides, certainly on the side of New Brighton, and with the assistance of dredging, to improve the channel of the Mersey over the bar.[2] Mr. Kinipple had proposed that training-walls should be put on the bar. He had suggested their being raised to 15 feet under low-water mark; but Mr. Vernon-Harcourt could not understand what he meant by that, because 15 feet below low-water level would be below the level of the bar. It appeared to him that, in any improvement of that kind, the chief point was to direct the out-

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[1] "Rivers and Canals," L. F. Vernon-Harcourt, p. 257; and Minutes of Proceedings Inst. C.E., vol. lxx. p. 29.

[2] Proceedings of the Royal Society of London, vol. xlvii. p. 142.

Mr. Vernon-Harcourt. going current between the narrows towards the bar, and not necessarily to carry the training-walls over the bar itself. Mr. Kinipple had also referred to the sluicing arrangements at the Canada Basin, which, he thought, were costly; but it would be evident, with the experience on the Mersey of the great amount of accretion that took place very readily in still water, that nothing less than what the Author had carried out would be sufficient to ensure the depth of water required over the sills. Mr. Kinipple, in dealing with training-walls at Greenock, on the Firth of Clyde, had a very different estuary to deal with from that of the Mersey. Mr. Vernon-Harcourt knew them both perfectly well, and they were as different as any two estuaries could be. Greenock was in a comparatively sheltered estuary; in the outer estuary of the Mersey, especially over the bar, they were almost in the open sea. There was, therefore, a considerable difference in the exposure of training-works in the two cases. Mr. Kinipple had further referred to the latest walls in the Liverpool Docks, which he considered too costly, as being of too great a section. But as far as his experience had gone, and he had had a good deal of experience of docks in different places, he thought that clay was one of the worst materials on which dock-walls could be built. Even a silty foundation with a wall on bearing piles, gravel or sand was much better for building walls upon than clay. There was great difficulty in ensuring a stable foundation so that the walls should not be liable to slip forward. The only certain way to secure the walls from slipping forward in such a case, was to carry the foundations down considerably below the dock-bottom level. He did not think the section of the Hornby Dock wall (Plate 3), could be regarded as an excessive section, under any circumstances whatever.[1] The Langton dock wall might be rather too large; but he thought that it was not far beyond the usual strength of dock walls, especially with such a variable water-level. The Liverpool Docks might naturally be contrasted with the docks in London. The former were continuous for 6 miles. They were much more visible than the London Docks, which were placed in the bends of the river, not stretching along the river bank. The London Docks, however, were mostly considerably larger in area; for the largest dock in Liverpool, the Alexandra Dock, was 44 acres, and the Huskisson Dock, 30 acres, as compared with the Tilbury Dock, 57¼ acres; the Victoria Dock, 74 acres; and the Albert Dock, about 73 acres. The total water-area of the London

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[1] "Harbours and Docks." By L. F. Vernon-Harcourt, vol. ii., plate 14.

Mr. Vernon-Harcourt.

Docks was 558 acres, as compared with 545 acres at Liverpool and Birkenhead together. There was a disadvantage sometimes in making very large docks, because, unless a system of jetties was arranged, there was not the same amount of quay length in proportion to the area as in the case of smaller docks; but he imagined that the Alexandra Dock pointed to the conclusion that if the Author had been able to re-model the whole of the Liverpool Docks, he would not have made them so small, because they required a number of entrances, and were therefore more costly to manage than larger docks with a proper arrangement of jetties, like the Alexandra Dock, which seemed to him to be a very good type of dock. Then, again, Liverpool existed for the docks, whereas London existed for many other purposes; therefore the Liverpool Docks exercised a greater importance in regard to Liverpool than the docks of London could possibly exercise in regard to London. The London trade was larger than the Liverpool trade taken altogether. Its import trade was considerably larger, and was increasing more rapidly; but its export trade was less than Liverpool. Liverpool was situated near the manufacturing districts; whereas the trade of London was in a great measure required for the supply of London itself. As to the arrangement of the docks, owing to the great rise of tide at Liverpool, as compared with London, a different system of access had been adopted, namely, entrances and half-tide docks; whereas in London, locks had always been adopted, to enable ships to get in at most states of the tide. In many cases, however, in the London Docks, there were basins fulfilling the purposes of a half-tide dock, so that a level was formed before high-water, and allowed vessels to go straight into the basin, which could be drawn down without inconvenience to a lower level than the dock itself. There was, therefore, not so much difference between the systems adopted at London and Liverpool as might appear in looking only at the different arrangements of locks and entrances; because the basins afforded considerable facility in London for getting vessels into and out of the docks. The width of some of the entrances at Liverpool was much larger than anything in London. There were entrances at Liverpool and Birkenhead 100 feet wide; whereas in London, the largest entrances were only 80 feet wide. There were also entrances of 100 feet width at Barrow and at Havre; but he did not know of any others as wide as 100 feet. In London they had never exceeded 80 feet; and now at Liverpool they had come down to the smaller width of 65 feet, on account of the disuse of paddle-

Mr. Vernon-Harcourt.

wheel steamers. Liverpool had the advantage of having all the docks under one control; whereas in London, they were under separate companies, and separate control. Undoubtedly one disadvantage in Liverpool in future would be that there would be more difficulty in dock extension than in London. Here the area of dock extension was for the present practically unlimited; whereas at Liverpool, though there were great differences in the extensions north and south, the north docks being formed on reclaimed land, and the south docks being excavated from the side of the hill, there would no doubt be increasing difficulties in forming dock extensions, not because there was not plenty of space at the north for reclaiming land for the docks, but because of the exposed nature of that site. He agreed with Mr. Giles in considering that there seemed to have been too little attention paid to the question of railway sidings in the docks. When he went over them he was surprised at the difference they presented in this respect to the small Garston Docks, which he examined on behalf of the London and North Western Railway Company in 1884. The contrast was very striking. The Garston Docks, belonging to a railway company, were wonderfully well supplied with railway appliances; whereas the Liverpool Docks were very inadequately supplied with sidings. With reference to the Pluckington Bank, Mr. Kinipple had suggested that the river should be narrowed on the opposite shore in order to remove the bank by increased scour. Mr. Vernon-Harcourt thought there might be some difficulty in narrowing the river in that way on the Cheshire side, because this would tend to interfere with the channel leading to the Sloyne. He thought the Pluckington Bank was not merely due, as stated in the Paper, to the deflection of the ebb current from Dingle Point, but that it was also due to the narrowing of the river opposite the centre of Liverpool, expanding into a wider channel above, which naturally led to deposit; and though it might be possible to remove it by narrowing the river higher up without interfering with the tidal flow, he thought it would be a delicate matter; and it was also, perhaps, questionable whether another plan, namely, that of putting docks upon the Pluckington Bank itself, would be a feasible engineering undertaking. Though opinions might differ as to the way in which the improvement of the bar should be carried out, and to what extent sidings should be introduced on the Liverpool quays, all engineers would agree that the Author had displayed remarkable ability in the sluicing arrangements for the Canada Basin, and had rendered great services to the Mersey Docks and Harbour Board in the extensions he had carried out both to the north and south for the port of Liverpool. Mr. Vernon-Harcourt.

Mr. Kinipple. Mr. W. R. Kinipple explained, in reference to Mr. Vernon-Harcourt's criticism of his remarks on training-banks, that what he meant was that they should be commenced some distance inside the bar and extended up to and across the bar, as the sand was scoured away. With regard to his reference to the Clyde, he had made no allusions to removing a bar on that river; he referred to the Burry Inlet in South Wales.

Sir James N. Douglass. Sir James N. Douglass said that it was stated in the Paper that:—"The general range of tide must be considered as affording a comparatively convenient approach for even the largest vessels; nevertheless, as the tendency is towards a further increase in the size of ships, and when time forms such an important element of successful trading, a deeper channel would evidently be desirable. The attainment of such an end is, however, surrounded with physical and financial difficulties of no ordinary character, and though the question is kept prominently in view, no definite steps of magnitude have yet been taken towards its solution." He was sure that every member of the profession would endorse those words. At Liverpool there was a magnificent channel from the docks to the bar; that channel was well lighted and buoyed; everything seemed to be perfect for such an important maritime port, except the bar. Anything more deplorable for the interests of the port, and the shipping trading to it, could scarcely be conceived than the fact that several large steamers and sailing ships, approaching the bar of Liverpool with such weather as had been recently experienced, might have to dodge about in the most dangerous way in close proximity to each other for two or three hours, waiting for water to get over the bar. Mr. Shelford had referred to investigations now being carried out by a committee of the British Association, of which he was a member, on the action of waves and currents on the beds and foreshores of estuaries by means of working models. Sir James Douglass was also a member of that committee, and he might state that the experimental work, carried out by Professor Osborne Reynolds in the Whitworth Laboratory at Manchester, had so far been very successful, and it was establishing the important fact that the regime of such estuaries could be accurately determined by those working models. The first portion of the report of the committee was read at the last meeting of the British Association at Newcastle, and it would shortly be published. For such a case as Liverpool the most efficient and economical method to be adopted, for providing the

Sir James N. Douglass. desired permanent deep-water channel between the docks and the sea, could be determined by those working models at a very small outlay, before the channel works were commenced. It was, therefore, to be hoped that the Author would be empowered to proceed with the work, and crown the success and perfection of his work at the docks by relieving Liverpool, the first maritime port in the world, of a reproach that had attached to it for so many years—the want of ready access at all times of tide and in all states of weather for the ships that were now built and were being built.

Mr. Duckham. Mr. F. E. Duckham could quite understand that those connected with dock construction would be somewhat despondent, fearing that so much having been done in the construction of docks at Liverpool, London, Barry, Southampton, and other places, there would be very little more for dock constructors to do. But it must be borne in mind that, during the last ten years, there had been an increase of no less than 33 per cent. in the foreign trade of the United Kingdom, and that increase would no doubt go on to a greater or less degree for years to come. There would therefore be docks to make, and that being so, Papers like the Author's would be of great importance to those who might have anything to do with dock-designing or construction. He considered the Author had wisely flattened the sills of the Liverpool Docks, but he thought hardly enough. He should be inclined to have the floor of the dock entrance either entirely flat, or so flat that the versed sine of the curve should not be more than 12 or 15 inches. The Author, he believed, had adopted 36 inches in an entrance of 65 feet. He would briefly explain why he should do that. In the first instance, supposing a vessel to be entering the dock at such a state of tide that it would have very little more water over the sill than the water it was actually drawing, it would have to be kept quite in the centre of the lock to be able to get through without touching one side or the other of the invert. It might be that one of the men in connection with the dock, in his zeal to get through the work, seeing that there was plenty of water on the surface on both sides of the ship coming in, would say, "We will try to get this little vessel out at the same time," and the consequence would be a jam, and it depended if the tide was rising or falling whether there would be a disaster. Another reason was that the large cargo-carrying steamers of the present day had midship sections very much like square boxes. He had one in mind which came to the Millwall Docks with a rise in the floor of only 13 inches. Fortunately its midship keel was 11 inches, but this left only 2 feet between the turn of the

Mr. Duckham.

bilge and the level of the under side of the keel; moreover, many of the large vessels were fitted with bilge-keels, and, therefore, for all practical purposes in connection with getting them in and out of the dock, they might be taken as being level on the under sides, so that he thought the entrances of docks should be correspondingly level or nearly so. As to the depth of the water over the sill, the Author had, no doubt, accomplished much at Liverpool in securing 12 feet of water below datum. There were difficulties in the Mersey in getting a great depth of water, especially on the north side. The 12 feet below datum gave 23 feet 7 inches below high-water of ordinary neap-tides; but he thought that wherever possible no dock should be constructed for sea-going vessels with less than 26 feet of water over the sills at ordinary neap-tides. Respecting the statement that large vessels coming up tidal rivers invariably approached the entrance of a dock heading against the flood-tide; in the Thames and other rivers the entrances of docks could be seen turned in various directions, some up and some down, and some square to the tide. There could be no doubt that, for the purposes of navigation, vessels were much more under control if they could turn their heads down against the tide, when approaching the dock entrance; and having the dock entrance pointed up the river, the vessels could get into the dock more conveniently than under other conditions; but large vessels had scarcely an opportunity of turning in the dock, and so necessarily went out stern first. It was a special convenience to them to have the entrance facing up the river, the flood-tide would catch a vessel on the quarter, turn the stern up the river, and the head thus automatically down the river in the direction in which the ship was about to proceed. The Author had referred to the number of vessels taken in at the Canada Basin during one tide. It had been said that there must be two or three entrances to do such an amount of work in the time. The only record approaching it that he had was one at the Millwall Docks twelve months ago. A fog had lasted three or four days, so that there was a large accumulation of vessels and craft wanting to go in and out of the dock. When it cleared, thirteen vessels registering 14,718 tons managed to get into the dock, and nine vessels registering 14,464 tons to get out, in all twenty-two vessels registering 29,182 tons. In addition to that, seventy-nine barges were admitted and sixty-seven barges let out, so that the total number of vessels and craft let into and out of a single lock during that tide was one hundred and sixty-eight. It was, however, to be noted that the work done

Mr. Duckham. at the Canada Basin was accomplished in a little more than two hours, while the quoted work at Millwall occupied nearly eight hours. He had referred to square sections of vessels. It had been for some time past a puzzle to him why dock walls were made with a batter. Taking the case of a wall battering an inch to a foot, the bilge of the vessel, which might be about 24 feet below the coping, would be grinding against the wall, and there would be a space of 24 inches between the coping and the side of the ship. The grinding was going on down below between the wall, where it could not be got at for repairs, and the part of the ship where damage was more likely to be done; while at the quay level there was a gap of 24 inches, which was not only a source of danger to the passengers along the quay, but a place where any packages that happened to be loose in the slings were sure to tumble into the water. That would happen, because in coming ashore they were likely to be touched by some portion of the rigging, and being loose they would easily drop. He thought if the walls were vertical (and he did not see why they should not be), it would be much more safe and convenient for dock work. He had always looked upon sluicing as unprofitable. Some 40,000 or 50,000 tons of water, which had been in the dock eight or ten hours, and had so got comparatively clean, were let out and scoured away a small portion of mud in the vicinity of the sluice outlet. But when the tide rose again, there was admitted into the dock a corresponding quantity of water, which carried with it a large mixture of mud, and generally the quantity of mud deposited in the dock by the dirty water was considerably in excess of the mud scoured away from the entrance channel. At Liverpool, no doubt, there was an exception to the rule to which he had referred. The Author had stated that a certain quantity of water had to be got rid of to lower the level of the water in the basin, and that being so the arrangement of the sluices seemed one which he did not think could be improved upon. It had effected the object wonderfully well. There was a system in practice at Tilbury Dock of forcing water down, which acted efficiently for the removal of the mud without dredging. He should be glad if the Author would give the relative cost and efficiency of the zinc roofs as compared with ordinary slate roofs. In docks where sheds were so extensive the cost of maintaining the roofs was a serious item; and if it was possible to improve upon slate roofs, it would be a very good thing. He had already said that the increase in the foreign tonnage of the United Kingdom had been 33 per cent. during the last ten years. The

Mr. Duckham. increase in the port of London during the last ten years was 40 per cent., while in Liverpool it was only 22 per cent. It was a question whether the non-participation of Liverpool in the average increase did not to some extent arise from the difficulty of getting ships over the bar. He believed that the word "impossible" existed in the English dictionary; he did not believe that it existed in the dictionary of English engineers; and he had no doubt that when the Author had the reins given him to carry out the work, that which had been referred to as a reproach to Liverpool and to the engineering profession would be removed.

Mr. Manning. Mr. A. MANNING stated that the Tilbury Dock Basin was of about 17 acres, with a depth of about 26 feet at low-water of spring-tides. In that basin, as might be readily supposed, a large accumulation of mud was deposited, and the mode adopted for getting rid of it was the use of a combination of harrows and high-pressure water-jets towed from the quarters of a small tug about 70 feet in length. The tug worked about six ebb-tides in the week, and thus kept the Tilbury Basin entirely clear of mud; the water-jets were also found very serviceable for washing away the mud from the lock, and generally clearing away a great deal of mud that had hitherto been removed by spoon barges at greater cost. The matter was one upon which, during the construction of the docks, he had had the advantage of several conversations with the Author, who strongly advised him to put down a system of pipes and sluices like that adopted at the Canada Basin. Mr. Manning's objections were, first the cost, and secondly, he did not consider that sluicing from the water in the dock, with a head of only 18 or 20 feet, would be sufficiently effective in 26 feet depth of water. It was very different when there was only 3 or 4 feet depth of water over a concrete bottom, as in the Canada Basin. He therefore determined to wait and see the result of the accumulations of mud, and apply some ambulatory system of sluicing instead. He did not know that the method adopted was an original idea, but the gentleman who superintended the work under him at the time was strongly impressed with the value of using high-pressure water-jets. Previously chain harrows merely had been used. He was bound to say that the addition of the water-jets added materially to the success of the operation. It might be roughly stated that the system accomplished in six tides more than would be done in twelve tides without their aid. The water-jets, he believed, worked at about 80 lbs. pressure per square inch, having an effective pressure of about 60 lbs. at the bottom of the dock. A great deal had been said about the absence of railway sidings

Mr. Manning. at the Liverpool Docks. An important factor in determining the arrangement of docks was a consideration of the trade of the town in which they were placed. He had given the subject of railway accommodation primary consideration in the arrangement of the Tilbury Docks, which docks were like a large railway goods yard. In arranging the sidings of docks great care should be taken that every quay should be approached by workable curves, and it should not be necessary to have turntables in any place for getting trains to and from the quay side. At Liverpool the railways coming into the town were not very conveniently situated, even if the system of the merchants there permitted of any large extent of railway business being done; but it was clear from the system adopted by the shipowners of discharging their own ships, and the merchants warehousing their goods in their own warehouses in the town, that an elaborate railway system at Liverpool would be practically thrown away. From what he had seen, he thought the railway accommodation provided at Liverpool was far in excess of any use that was made of it. Credit should therefore be given to the Author for having arranged the docks in a way that suited the character of the trade of the town. One matter had always been a subject of regret to him since he first saw the early part of the works of the north end extension—namely the question of depth. Considering the facility with which the bank had been moved by the sluicing arrangement, it would have been very desirable to make the entrance into the Langton Dock and the Canada Basin at least 5 feet deeper. He did not believe there would have been any practical difficulty in keeping the bank clear, even by the arrangement of sluices which the Author had so successfully adopted. It was undoubtedly most objectionable and most detrimental to the business of a great port like Liverpool, having weekly services of Atlantic liners, when presumably every other week the vessels were unable to enter the dock by reason of the low high-water neaps, or could not finish their loading in the docks for fear of being beneaped on the day they had to sail. It involved a great deal of most unpleasant and dangerous work in commencing the discharge and finishing the loading of big ships in the Mersey, and he hoped the time would come when a new entrance into those splendid docks at the north end would be made, with a sufficient depth to admit of vessels being docked at high-water of neap-tides—which could not be done at the present time. Mr. Duckham had referred to ordinary neaps as giving 23 feet 7 inches at the sill. He believed that the low neaps given in the Tables were only 20 feet 8 inches—a depth manifestly useless to vessels loading to 26 or 27 feet. No doubt great importance had been attached to the question of dealing with the bar of the Mersey. He only desired to point out that unless some scheme could be adopted by which the bar could be removed, so as to give from 4 to 5 fathoms of water where now there was little more than 1½ fathom, it would scarcely be of practical utility to Liverpool. Nature for many years, he might say for many centuries, had maintained the depth of water over the bar in the Mersey at very much its present condition. True, it had shifted and required constant attention. But, according to the oldest records of the Hydrographer's office to which he had referred, there did not appear to have been any material difference in the depth of water on the bar. Of course training-walls would to some extent tend to increase the scour; but there was one point that might be gathered from the study of the best charts of the Mersey estuary, as being a very important consideration, and one which he thought operated materially against the success that some engineers anticipated from the construction of training-walls, namely, the long distance outside the bar at which the bottom of the sea was nearly level. He believed that from the present bar a depth of 10 fathoms of water was not reached in less than 8 or 10 miles. It was therefore almost certain that training-walls would merely have the effect of shifting the bar further out, and that they might be extended for 8 or 10 miles before the bar was effectually dispersed by their action. Of course engineers naturally liked to see large corporations finding money for interesting experiments; but he thought the question should be approached with very great care, and he was not at all sanguine about the result. Mr. Manning.

Sir JOHN COODE asked if Mr. Manning could state the length, breadth and depth of the deposit outside the dock entrance at Tilbury. Sir John Coode.

Mr. MANNING said it was a daily deposit. The fresh deposit each day would only be about 1½ inch or 2 inches; it did not extend into the river beyond the range of the pier heads. Deep water was reached a very small way outside, and the mud soon got dispersed. Mr. Manning.

Mr. A. C. HURTZIG said that the Author had emphasized the importance to the welfare of the port of Liverpool of having docks with deep sills, and proceeded to show how necessary it was to scheme an arrangement by which the depth on the sills should be maintained after the docks were constructed. He had fully described the interesting arrangement that he had brought out for those Mr. Hurtzig.

Mr. Hurtzig. sluices. When the north extension works were under construction, Mr. Hurtzig had an opportunity of going through the sluices on one or two occasions, and he was much impressed with the magnificence of the work, and had watched their results with interest. The Author had stated that the estimated cost of the north extension works was about £2,727,000. He should be glad to know the estimated cost of the same works, supposing the sluices had not been constructed, and the walls had been made solid in the usual way. The Author had said that he declined to resort to such "expedients," as he had called them, as dredging. Deep sills were as important to other ports of the country as to Liverpool, and deep sills had been elsewhere constructed. Mr. Abernethy, Past President, had constructed the Alexandra Dock at Hull, whose sill was 14 feet below low-water of spring-tides. In making the approach to that sill, he had dredged an artificial channel through a hard clay bank, to the extent of about 30 or 35 acres. The depth of the water at the commencement of the works was 2 feet at low-water of spring-tides, and he had dredged it to 12 feet at low-water of spring-tides. Since the opening of the dock in 1885, one single-ladder dredger had been at work at the entrance. The depth of the water was 34 feet at high-water of spring-tides, and 28 feet at high-water of neap-tides, and the annual cost of dredging the artificial channel over the 30 or 35 acres had been about £4,000, including everything. The area of the Canada Basin was 9½ acres, and of the trumpet-shaped entrance 3½ acres: in all 13 acres. He might point out that the Humber at Hull was quite as exposed as the Mersey at the Canada Basin. There was a fetch of 14 miles down towards Grimsby and 21 to the Spurn. The river was nearly 2 miles wide opposite the entrance. The seas there, although not reaching the 15 feet above high-water mark which the Author had referred to, were very heavy on occasions, and the dredging in the Humber, he imagined, was as difficult as it would be in the Mersey. The cost of £4,000 a year capitalised would be £100,000. The Author had only 13 acres to deal with, and if he had resorted to such a plan as dredging, he would probably have saved a quarter of a million of money by not constructing the sluices. He did not say that the sluices were not efficient, or that they were not a splendid monument of the Author's engineering skill; but financially he believed they were not what they might be. He wished to refer to one other point with regard to the Pluckington Bank. Mr. Shoolbred in 1876 had read a Paper before the Institution on the estuary of the Mersey, in which he gave three or four outlines, and capacities, of the Pluckington Bank at different

Mr. Hurtzig.

times for different years.[1] It would be, he thought, of value to the Institution if the Author could supplement his Paper by the most recent survey of Pluckington Bank, showing its present condition. He had stated that the bank was due to the diversion of the tide by the rocks at Dingle Point. If that were so, how would it account for the increase of Pluckington Bank? Such increase had been progressive and almost corresponding with the continuation of the walls down towards the mouth of the Mersey, which, he thought, had deflected the flood currents to the Cheshire shore more and more, in consequence of the smooth and advantageous channel which they formed for the tidal current. That increased deflection of the tide, he thought, was the cause of the increase of Pluckington Bank, whatever might be the cause of its origin. It would not be possible, perhaps, to remove the Pluckington Bank. The Author had met the case in an ingenious way by having a continuous chain of docks from the south end, which rendered it unnecessary to approach the older docks by crossing Pluckington Bank. That was perhaps the best way out of the difficulty, but it would be interesting to know what was the most recent condition of this Bank. He could not say much as to the bar. The interesting and splendid model which Mr. Shelford exhibited gave an excellent idea of the subaqueous condition of the bed of the estuary. Whatever was done would of course have to be conducted on a large scale, but the principle to be borne in mind was that the tidal water which accumulated in the upper estuary should be constrained to go out from the river through one channel only. Therefore, all the subsidiary channels through the different Burbo Banks should, if the engineering question alone were considered, be rigidly closed in some way, and something should be done to prevent the diversion of the main channel into the old Formby outlet. In that way the effect of the sea waves in pounding up sand and forming a bar would be largely counteracted; the bar would be sent much more to seaward, if not entirely dispersed. No doubt the financial difficulties were very great, and there were the vested interests of the coasters to be considered, so that the whole subject should be approached with the greatest caution.

Mr. Capper.

Mr. R. Capper said that the Paper was so explicit that he, as one who was apprenticed to the management and working of docks in London, felt great difficulty in finding any question to ask respecting it. The Author had given the length of the double

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[1] Minutes of Proceedings Inst. C.E., vol. xlvi. p. 29.

Mr. Capper. storage sheds and the area, but he had not given the cubical storage capacity per lineal foot of quay frontage. He saw no limit of safety for storing on the upper floor, so that he could not work out the cubical capacity himself. If the Author would kindly give that information, it would be very valuable; and it would also be interesting if he would supply a diagram of Toxteth Dock sheds, showing an actual distribution of a ship's cargo upon the floors, because he thought that the horizontal area was only about equal to the vertical area of the cubical contents of the ship. With reference to the powers granted by the Act of 1873, and the extension of the construction of the works over a period of eight or nine years, would the Author state what percentage had had to be added to the actual cost for interest during construction? With regard to the trade of London and Liverpool, nearly all the vessels that went into the Mersey entered the docks, but that was not the case in London. It was stated in the Paper that the revenue from all sources derived from 18,000,000 tons of shipping was £2,500,000; this was *2s. 9d.* per registered ton. It was well known, however, that the gross income of the docks in London per ton of shipping was *10s.*

Mr. Williams. Mr. J. Evelyn Williams said that, however complete these great dock works might be, he was of opinion that no time should be lost in sweeping away the bar, which formed practically the sill of the entire Mersey Dock Estate. It was stated that the navigating depth over the bar at lowest low-water of spring-tides was 10 feet, and that the range of the tide was 30 feet at springs, while neap-tides had a range of 10 feet, with a high-water 20 feet above low-water of springs. Thus the depth of water on the bar at high-water of spring-tides was 40 feet, and at high-water of neap-tides 30 feet. It seemed obvious from this, that the normal level of mean low-water was 15 feet above the bar; therefore, to allow modern express Atlantic liners to run up the Mersey, even at mean low-water level, would entail the lowering of the bar about 10 feet. He was well acquainted with the bar, and had sailed over it frequently under all conditions of weather and of tide; and he felt sure that if its removal should be decided upon, success would be assured under the local knowledge and guidance of the Author of the Paper. He questioned, however, whether the removal of the bar could be permanently effected by dredging operations alone. In so open and exposed a position it might possibly happen, during a heavy gale, that the works of a year would be obliterated in twenty-four hours. To afford a permanent deep-water channel, he was inclined to concur with the opinion as to the necessity of closing the secondary and minor outlet to the sea locally known as the "Rock Channel." This work, he thought, would be less difficult than the closing of the old sea channel of the River Witham, which he effected only a few years ago. It would also, he thought, be necessary to close any minor channels lower down, so as to concentrate the scour in the main channel over the bar, and at the same time afford protection to the dredging operations within. Mr. Williams.

Mr. Grover. Mr. J. W. Grover believed that if the stream in the estuary could be confined to one channel, instead of being allowed to spread about over a number of channels, force would be obtained to scour away the bar. The difficulty was how to do it. Some twenty-five years ago he had seen an extensive system of training-walls carried out at the mouth of the River Maas, for a small sum of money. The Dutchmen formed mattresses of osiers, which were taken down by barges, filled with stone. When they got them into position they threw the stones upon them and sank them. The same thing was done in the Wash by Mr. Wheeler about fifteen years ago on an extensive scale, though with this great difference, that he did not tie the fascines together, but simply threw them over and clay on the top of them. But although the depth of water was nearly 20 feet, the works were not in an open sea-way like those at the mouth of the River Maas. He would suggest whether it might not be possible to carry out works of that description at Liverpool. Five years ago Mr. Grover had carried out some embankments and sea-works at the mouth of the River Dee, and he used faggots very largely, for which he paid 12*s.* 6*d.* a hundred. So far as his experience had gone, he believed that the cost of a work of this kind need not exceed 2*s.* 6*d.* per cubic yard. The mattresses were made smaller and smaller as the work gradually emerged out of the water. The cost of the works on the River Witham was only about 1*s.* 8*d.* per cubic yard. He therefore thought that his calculation was not very far from the mark, especially when it was considered that, instead of using clay, he should propose to use stone. No doubt the Rock Channel, which was a-wash at low-water at the mouth should be closed up. Formerly it was the channel connected with the Dee, and coasters, ships, and boats used to go along it; but now there was a large bank, called Hoylake Bank, at the mouth of the Dee on the north side at the end of the channel, which he believed stopped up the passage so far as any practical utility was concerned. In the same way if the Formby Channel on the north side were stopped up, the power of the ebb would be sufficiently strong to carry away the bar.

Mr. Walker. Mr. CHARLES R. WALKER said, that while acting as Resident Engineer for the Harbour Commissioners of the Isle of Man, he frequently had to visit Liverpool, and consequently he well knew the violence of the storms on the bar of the Mersey. He was afraid that training-walls of either rubble stones or of weighted fascines would not be able to resist the force of the sea in such an exposed situation, and that the stones would be washed into the channel, to be afterwards removed at great expense. He believed the best plan would be to deepen and improve the present channel. If the sand, after it was dredged or pumped, had to be taken away by barges, he thought the progress of clearing out the channel would not be very rapid; but if the sand were disturbed by harrows drawn by a tug during the ebb-tide, the out-going tide would readily clear it away. He considered that the method of propeller sluicing, recommended by Mr. R. A. Habersham, for the removal of shoals in the Columbia River, and described by Mr. H. Hawgood,[1] well worthy of trial. It had proved effectual in that case, and he was persuaded that an experiment carried out on the Mersey bar in the same way, as detailed in the Paper referred to, would give a favourable result. With regard to the removal by sluicing of the silt at the Canada Basin and entrance, although this was evidently done by the water drawn from the docks, which necessarily reduced the head at spring-tides, yet as it was stated that as much water as possible must be retained to give flotation to the vessels in the inner docks at low neap-tides, perhaps the Author would kindly explain how he then obtained the water for sluicing. Possibly this might be procured by pumping water from the river into the docks by a set of large centrifugal pumps. He did not think that a better or cheaper way could be devised for clearing away the mud than that adopted by the Author, whose idea of utilizing the surplus water in the docks at spring-tides for the purpose of sluicing, would, he considered, be of much value in the future designing of docks for localities where there was a great rise and fall of tide.

Mr. Lyster. Mr. G. F. LYSTER, in reply, said that Sir Robert Rawlinson had gone back to ancient history, and had referred to the late Mr. Jesse Hartley, than whose works, particularly those in masonry, there never were better examples of sound engineering. Sir Robert Rawlinson's name too was well known amongst the engineer's staff at Liverpool, even the youngest of whom looked up to the position which he had achieved, and attempted to follow so excellent an example. The masonry adopted in Liverpool varied in kind. In the river

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxiii. p. 386.

walls, and parts exposed to the heavy action of the sea, it was of a massive and cyclopean type. The stones were irregular in form, but fairly well bedded, and jointed from 8 to 9 inches back from the face. The face was known as "rock face," and the whole was set, not as Sir Robert Rawlinson seemed to think, in cement, but in lime mortar. It was pointed 1½ inch in from the face with Portland cement, the joints being all exceedingly well kept up. The second type was that comprised in the masonry of the dock entrances, chambers, locks, nibs and pier heads. That was also of the same class as the outside work, but with the difference that the cyclopean character was not so carefully carried out as regarded size. As Mr. Hayter had indicated, a considerable amount of small stone was used, but always with a sufficient number of large stones to insure good bond; it was "chisel-drafted" and "punched" on the face, also set in lime mortar, and backed up with large masses of red sandstone. The masons employed were very ready at that class of work, and were able to put it together rapidly, without the extreme cost which might be expected by a stranger looking at the completed work. The inner dock masonry was composed as a rule of red sandstone; it was all square on the beds and joints, and it was also pitched and dressed on the face, so as to present an even surface to the rubbing of the ships. It was coped with granite in all cases. The granite was irregular in form, sometimes bonding two or three courses into the body of the work, and at other times stretching along three or four courses. He had adopted the cyclopean class of masonry very largely at Guernsey, because the granite in that island was of a dislocated character, not like the Cornish granite, but only obtained in irregular blocks, somewhat similar to that which he got from the Mersey Docks and Harbour Board's quarries at Kirkmabreck, Kirkcudbrightshire. The Kirkmabreck granite work might appear costly at first sight, but it was by no means so considering the circumstances. Quarrying granite in large blocks gave an opportunity of getting a considerable quantity of the smaller material which was used for pinners, which Mr. Hayter had referred to, and which, as a rule, were deeply bedded in the body of the wall. There could be no doubt that this class of masonry served its purpose admirably, presenting a hard surface for vessels to rub against; and that surface was obtained as cheaply as possible by the use of granite in any shape that came to hand, and without much labour on it. There could be no question of its durability; none of the stones ever got displaced, and the wall so built practically required no repairs. At the quarries, stone, such as was suitable for paving, was all set Mr. Lyster.

Mr. Lyster. aside and formed into setts, which were brought ready dressed to the quays. Though it was not of the hornblende character, it was hard, and made an excellent pavement. The sandstone was procured from Runcorn in large ashlar blocks. He did not use much of the ashlar, but whatever he did use was delivered at a cost from 7*d.* to 8*d.* per cubic foot. The large backing was delivered at 4*s.* 9*d.* per ton. Stone for walls cost about 5*s.* 9*d.* per ton, and rubble about 3*s.* per ton. For the granite ashlar from Cornwall he paid about 2*s.* 6*d.* per cubic foot, and the granite from the Dock Board's Scotch quarries was delivered on the quay at Liverpool at a cost of about 2*s.* per cubic foot. The granite rubble, large and small, which was employed in facework of walls, however, cost about 8*s.* per ton, equal to about 7½*d.* per cubic foot. The mortar was of blue lias lime from the Halkin mountains in Flintshire, and was delivered in lumps about the size of cocoa-nuts on the quays close to the mortar mills, where it was burnt and ground. The mortar used varied according to the position in which it was to be employed. The best quality consisted of 4 parts of lime, 3 parts of sand, and 1 part of smithy ash ground together for forty minutes, and it cost about 11*s.* per cubic yard. He had learned mortar-making from Mr. James Meadows Rendel, Past President, who set great store on mortar-making, and gave him his first lessons in it. He had also followed in the footsteps of Mr. Jesse Hartley, who justly prided himself on his mortar. The cost of masonry in the ordinary run of dock walls was about 18*s.* to 20*s.* per cubic yard, and about the entrances 25*s.* to 27*s.*, including the cost of hollow quoins, sills and such like specially dressed work. The Portland cement was obtained from the London district, and at the present time cost about 39*s.* per ton; but during the construction of the works described the general price was much higher. He used neat cement for pointing; the composition of the concrete was generally 8 portions of gravel to 1 portion of cement. The gravel was obtained from different points of the Welsh and Lancashire coasts and from the Isle of Man. With regard to the criticism of the section of the retaining-walls, he could not endorse the principle which Mr. Kinipple seemed to lay down, that the depth of directors' pockets should determine the section of retaining-wall to be adopted. He preferred to rely on his own judgment and experience in such matters, feeling certain that the ultimate result would be more economical. The section of the Hornby Dock wall, though its base was wide, was certainly on the light side, being about 56 superficial yards for a wall having a clear height of 37 feet. He therefore thought Mr.

Vernon-Harcourt had taken the correct view in contending that **Mr. Lyster.** this wall could not be regarded as of excessive section under any circumstances whatever. As the class of filling most desirable was not forthcoming for most of these walls, and as they had generally to be backed up very rapidly, they were necessarily constructed of a somewhat heavy section, in addition to which they were all designed to carry a heavy surcharge, or quay load, the necessity for which was evident. To show that an undue factor of safety was not employed: in one instance, where the backing up was very rapidly carried on, the wall showed signs of failure, but by prompt measures the movement was checked. In this matter of dock walls, he had not been entirely without that education which arose from a study of failures. The strong boulder-clay, found on the site of the Liverpool Docks, formed an excellent foundation, greatly superior, in fact, to London clay, which no doubt Mr. Vernon-Harcourt had in mind when referring to the question of foundations. The system of sluicing adopted was an important feature of the works, and involved very anxious consideration on his part. The Birkenhead Docks entrances, as designed by the late Mr. John B. Hartley, had outer sills laid at the level of 12 feet below the dock sill, or 2 feet below the lowest low-water. Unfortunately Mr. Hartley's health broke down, and he was not able to carry the works out, so that it devolved on Mr. Lyster to complete them. In carrying out the works he perceived the great value of deep sills and also of sluicing. He did not quite accord with the tradition existing in Liverpool that deep sills could not be constructed on the Liverpool side of the water. On going to Parliament, in 1873, for the large dock scheme, he was asked at what depth he thought of putting the sills. He had thought of 9 feet, but in the meantime had tried several experiments and decided upon 12 feet. He said to his Board, "If we go to 12 feet we must have works of a character that will ensure the depths of those sills and platforms and approaches being maintained." The result was the large system of sluicing. He thought that without that system of sluicing the north works could not have been maintained. He was aware that there were rivers in England more highly charged with silt and sand than the Mersey; but there was no doubt that that river carried an immense amount of matter in suspension at all times, and more especially when there was a gale of wind, or a heavy flood from up country; and wherever there was a quiet place it let its load of silt and sand drop. Whether the open basins were right or wrong, the water deposited the silt on the floor of the basins and docks

Mr. Lyster. That presented itself to him as a matter of great danger. The ships entering the docks were of enormous size, ranging up to 10,000 tons, nearly 600 feet long, over 60 feet beam, and drawing 24, 25, or 26 feet of water. It was important that they should get into dock, because anchoring in the river meant discharging cargo at a considerable loss. They ran, he would not say risks, but narrow shaves; they did not hesitate to enter a dock with a few inches of water under them. As a rule he kept the platforms, entrances and approaches to the sills, in the fairway 2 feet below the level of the sill. The sand and silt would accumulate in a night after a heavy gale of wind to a depth of several inches, and if a vessel came in with but little water beneath it might be a matter of very great danger. He had known vessels, worth with their cargo perhaps half a million sterling, come in with 8 inches between their keels and the sill. He did not think it right to jeopardize such valuable property; but desired to be absolutely certain that the platforms and sills were clear. He therefore swept the floors, as a room should be swept, every morning, by letting a certain volume of water out, and any little accumulation of silt could be turned back into the river by opening the sluices. He was aware that the cost of the sluices was considerable, but he could not now separate that item from the cost of the remainder of the work. He thought dredging would be a source of serious danger. He was aware that in the Tilbury Docks a vessel moved round the basin and stirred up the mud, and that the effluent current took it back into the river. That was excellent; but he was inclined to think it would not suit the circumstances at Liverpool. He should never rest satisfied if he had that operation going on, fearing that vessels might be caught and might take ground on the sills or in the basin. The Dock Board once had experience of that kind, and had to pay £70,000 for the loss of a vessel that had stuck in the lock from an accumulation of silt. That was before his day, but it taught him to make quite sure to provide proper sluices for the work to be done. The Langton Dock and the entrances were opened in 1881, and they had been in operation ever since. He had an examination made periodically by an expert diver, who walked over the bottom of the basin every spring-tide, and reported as to whether any of the concrete had been disturbed, or the caps of the up-cast nozzles moved; so far everything had been reported as in perfect order and working admirably. No one valued dredging more than he did in its proper place; but he could not admit that dredging in a basin leading to the fairway of a dock was proper. For what was dredging? It

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was the removal of something out of place—a sandy encumbrance. Dredging was unsuitable for the removal of a deposit of a few inches depth only; the dredger must penetrate 2 or 3 feet, and if a depth of 2 or 3 feet of sand were allowed to accumulate for the dredger, vessels would run great risks of being caught in the entrances and breaking their backs. That was one of his reasons for facing the expenditure incurred in going to a depth of 12 feet. He might mention as an open secret that the Dock Board was now considering the propriety of providing much deeper sills, in the reconstruction of some of the old docks in other positions on the Liverpool side of the estate. Plans were before the Board for that purpose. It was very objectionable that any vessel should ever be compelled to discharge goods in the river; and it was his duty to endeavour, as far as possible, to assist the Board in providing deep-water dock accommodation, and he was at present considering the subject. Whether sills deep enough to allow of vessels drawing, say 26 feet, entering on all tides would be decided on time would show. He concurred with Mr. Duckham that it was desirable to have dock sills so low that a vessel drawing at least 26 feet of water might enter on any tide. The question of providing and maintaining that depth in some situations was a most important one, and in none perhaps more so than in the case of the Mersey Docks, where the range of tide was very great. To accommodate many vessels now in existence, the floor of an entrance should be practically level in cross section if full advantage was to be taken of its depth in the centre. For the vessels of the present day, the effective depth of entrance of many of the older Liverpool Docks was much less than their nominal depth, owing to the great rise in the haunches of the sill inverts. The forms and proportions of vessels had varied very much from time to time, and of late years the tendency in the design of great Atlantic steamers had been to increase both their length and width; so that it appeared necessary for the dock designer to allow large margins in width in designing new entrances, and to allow plenty of room in the docks themselves. The tonnage which he had quoted as having been worked through the Langton entrances in two hours twenty minutes was that passed through both entrances between Langton Dock and the Canada Basin. The latter basin, it would be seen, served four other entrances, and the opening from the basin into the river was about 400 feet wide. About the year 1879 one of the many minor changes of the Pluckington Bank resulted in its extending itself so far to the northward as to endanger the great landing stage. It came under the stage for a

Mr. Lyster. considerable distance, the consequence being that the pontoons on which the deck of the stage rested took the ground. They were not much more than boxes of iron, and several of them were crushed at various times, so that the condition of the stage caused great anxiety. He had then to consider how best to deal with the matter. Many proposals were made, and one of them was in the direction of shifting the stage further northward. He was opposed to this, inasmuch as shifting it further northward would have interfered with the entrance into the Prince's half-tide dock, and have prevented it from being fully used. What struck him was that as the tail of the bank projected under the stage, the best thing would be to cut it off by sluicing, and he accordingly constructed a series of large sluices behind the stage. He made the George's Dock, the Canning, and the other docks to the southward, the reservoirs for the water, and he put in a system of pipes along the foreshore in front of the river wall, namely, between it and the stage. The valves were lifted at low-water when the working of the docks would allow of it. They ejected a vast volume of water, cutting off the tail effectually, so that there had been no trouble since they had been set to work.[1] As they were limited to about 400 feet in length, parallel to the river wall, the tail sometimes made its appearance further northward; but as long as the interval between it and the main body of the bank was kept clear, it did not cause much apprehension. With reference to the roof cranes, he thanked Mr. Hayter for his remarks on behalf of Mr. Lyster, Jun., who was the designer. In 1878–9, when the question of bringing grain in bulk to England became prominent, one of the points he had to consider was to deal with the grain brought as part cargo. Large ships came in with perhaps a few hundred tons of grain amongst other cargo, for the discharge of which it was not convenient that the ship should leave an ordinary berth and proceed to a special grain warehouse dock, and the difficulty was how to get rid of the grain. He thought the best thing would be to have American elevators to clear it over the side into barges, and then take it to another elevator on shore to raise and send it into the grain depots. The question was where to put the elevators, that they might be ready for use when required; and his son, Mr. A. G. Lyster, thought that the roof of the shed would be a convenient place, so that they could travel along the length of the shed and be lowered into any hatchway along the range, and effect the work of discharge over the side into a barge;

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[1] Minutes of Proceedings, Inst. C.E., vol. xc. p. 308.

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when that was done the elevators could be lifted up and replaced upon the roof out of the way. As, however, the shipowners were required to find such trade appliances at their own cost, the matter remained in abeyance, and floating elevators were introduced; but the roof crane, which, with the elevator, formed part of his son's invention and patent, came to the front. Referring to Mr. Kinipple's claim that he had designed precisely similar cranes; from the information he had collected in the matter, he concluded that no cranes of the special type referred to in the Paper had been constructed and brought into use by any one but himself. The crane which Mr. Kinipple described as being very similar, and having one leg on the coping and the other on the upper platform, was quite different to those in use at Liverpool, which were wholly on the roof, and this without alteration to the shed structure, except a slight additional strutting of the ridge-tree. Mr. Kinipple had evidently thought out a certain form of roof crane, and even designed one some years ago, but Mr. Lyster, under the circumstances explained, respectfully declined to acknowledge any claim for priority of invention or for bringing them into use. Mr. A. G. Lyster's crane was entirely on the roof, the slope of which it followed, giving no trouble. It was quite snug and entirely out of the way, but ready for use when wanted close to the ship, the sheds at Liverpool only being a few feet from the dock coping. The sheds were kept close to the edge of the quay on the theory of getting goods out of the ship into them as soon as possible. He had stated the amount of work that the cranes were capable of doing, and in his judgment they were admirable accessories to working a dock system economically and expeditiously. As regarded the general arrangement of the Liverpool Docks, on the foreshore of the Mersey land could not always be had exactly in the form best suited for docks for the largest class of vessels; but where the situation permitted, he thought that for the great ocean steamers, and for the trade as carried on in Liverpool, the Alexandra type of dock was the best, the body and branches being both of sufficient width to allow of the proper handling of vessels. This form gave the maximum berthage with a working minimum of water area. This led him to the subject of quay arrangements, a most important point, in connection with which was the question of railway accommodation. The trade of Liverpool was different from that of most other ports, inasmuch as it was not merely a terminus to one or more railway systems or water-ways; but it was a warehouse port, where goods imported must as a rule lie until a customer was

Mr. Lyster. found for them, and until it suited him to remove them for consumption. In the ordinary course of trade, therefore, goods had to be warehoused in Liverpool. Some were stored in the warehouses of the Dock Board adjoining the docks, others in the warehouses of the railway companies at their several receiving stations, and the greater portion in the warehouses owned by private individuals in the town; but he was not in a position to give the relative proportions of these several classes. Evidently, for the first and last-named classes, railways alongside the quay were of no benefit, and could not be used. For the goods intended to be warehoused by the railway companies, railway lines, it would be thought, must be of service. Against their use, however, had to be set the fact that most cargoes were made up of comparatively small parcels consigned to a great number of different people. Under these circumstances it was impossible to convert the dock wharf into a railway station; for in that case there would be four or five railway companies, with varying interests, all trying to get their wagons loaded, and their trains marshalled, which, without taking into account the lorries, carts and vans, could not be done on the limited quay space at command. It thus appeared that the best way to deal with mixed imports was to get them out of the ship, as quickly as possible, on to a roomy quay where they could be sorted, and where a cart could come alongside and remove them to their several immediate destinations. The only cases, therefore, in which railways could be usefully laid on the quays for import cargoes would be where ships of the "ocean tramp" class brought whole cargoes consigned to a few individuals. If there were a sufficient number of such cargoes destined for railway companies' warehouses or the country direct, it might perhaps be worth while to set aside one dock especially for that class of cargo, and lay out its quays suitably with rails. For outward goods, railway lines might be of service; but, here again, cargo steamers stayed so short a time in port, that the collecting of a cargo must be carried out in a very short time, and it must be brought to the quays while the ship was discharging. Thus, bearing in mind that several railway companies contributed their quota of cargo, great confusion would certainly result if railway trains were to bring down their cargo to the ship-side. Another factor, telling in favour of cartage, was that the quays and the streets of the town in their vicinity were very uniform in level, and the paving was generally excellent, so that the traction of road vehicles was so light as to compare favourably with rail traction. The only point in favour of railway loading would be the saving of one handling of the

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goods, against which there would certainly be drawbacks in getting alongside the goods, putting them on to the wagons, marshalling trains, &c., under the conditions indicated. In setting forward these explanations, he must not be understood as being in any way against bringing the railway as close to the ship as possible, or indeed as being responsible in any degree for the apparent lack of railway accommodation at the Liverpool Docks to which Mr. Giles had referred. The question of rails or no rails had prominently and unceasingly been before him for the twenty-nine years during which he had been Engineer to the Mersey Docks Estate. At the present moment there were 27 miles of railways along and through the docks and quays at Liverpool, laid down at a cost of not less than £70,000. Some of them, namely, the main lines, which ran fore and aft the estate, and joined up with the several (ten in all) railway goods stations abutting on the eastern margin of the docks, were freely and constantly used for the interchange of traffic from stations to the railway receiving depots. The remainder, about one-half of the whole quantity, were siding lines, which had been carried alongside some of the most prominent docks, and along the roadways and between the sheds. These, though laid at great cost for the purposes of carrying goods to and from station to ship, were in most cases absolutely never used. In some instances, in the most recently-built docks, he had been obliged to take up long lengths of railway which had been laid and never traversed by a single wagon, and he was now contemplating removing many hundreds of yards of track which had been laid about twenty years, and had never been used. He had joined in repeated conferences with railway directors, engineers, and managers, with the same results, that they never could see their way to use the lines; and he was informed by their traffic managers that it was more convenient and cheaper, under the special conditions of the trade of Liverpool, to transfer goods by lorry from station to ship-side, or from ship-side to station, than to marshal trains or move about isolated wagons for the purpose. The present method of working, though open to superficial criticism, might be regarded as having grown up under the special countenance of the railway companies themselves. If anything like a workable railway system, meeting the requirements and approval of the several parties concerned in the transfer of goods to their several destinations, were agreed upon, he should endeavour to give effect to their wishes. As Mr. Giles had pointed out, it was essential, if steamers of great value were to be worked profitably, that their stay in port should be as short as possible, and therefore cargo had to be discharged rapidly. From

Mr. Lyster. this point of view there was no question that discharge into a roomy shed could be effected far more rapidly, and with less risk of damage from weather, than into wagons, however well the lines of railway might be arranged. This was a question of traffic management, well worth the attention of dock engineers. To bear his view out, he had the authority of a traffic manager of one of the most important and recently-constructed docks in London, for saying that, in the case of that dock, the existence of railway lines in front of the sheds was a mistake, and that expense in land, as well as time and labour in working, would have been saved had the shed been brought as near as possible to the ship. He hoped, therefore, that the want of railways at Liverpool would not be considered inconsistent with the ideas of the present day, but rather that the arrangement of the quays would be taken to be the outcome of the special conditions of the trade of the port, which were entirely different from those obtaining at some other places, such as Southampton and Garston, which had been mentioned in this connection. In those docks at Liverpool and Birkenhead, where the conditions were suitable, such as the coal wharves, special rails and appliances were provided and freely used. The cost of zinc roofing, taking into account the lighter framing and boarding which could be used with it, was below that of slates. It was not, however, for this reason that he for the time adopted zinc for roofs. He should have preferred the older and well-tried material, even at somewhat greater cost; but when the great sheds of the northern extension were being constructed, there was no hope of being able to obtain suitable slates in sufficient quantity in the required time, and so, after full inquiries, zinc was adopted. It had, however, in places, been subject to rapid deterioration, particularly in sheds where boilers were used for steam-winches, and as it was no longer imperatively necessary to use it, he had reverted to slates as roof covering. The floors of the double-story sheds were designed to take a load of 30 cwt. on each square yard; these buildings ought not to be looked upon as warehouses in which goods were stored, but merely as sheds in which they remained for a short time till they could be sorted and sent off by road or rail to their destination. With regard to the revenue per ton of shipping at London and Liverpool, the figures in the Paper did not include any items for handling goods, which at Liverpool, except in the case of one or two enclosed docks, was not done by the Board. With respect to the claim that the honour of constructing the first tidal wet-dock belonging to London, and not to Liverpool, he could only say that although he never attempted to look up all information on the subject for himself, he had very good authority for his statement that the Liverpool Old Dock was the first tidal wet-dock constructed in England. Some years ago he had corresponded on the subject with the late Sir James Picton, well known as the historian of Liverpool, who then went into the matter very fully. Mr. Lyster would not then recite all the evidence brought forward, in which the claims of the Howland Great Wet-Dock, amongst others, were dealt with, but might quote the concluding paragraph of a report on his investigations, which ran thus: "I consider that the claim of Liverpool to the origination of the first public floating dock stands unimpeached." He wished to avoid re-opening the prolonged and complex discussion on the question of the effect of the low-water channel upon the condition of the upper estuary, which had been fully investigated during the consideration of the Manchester Ship-Canal Bill by successive Parliamentary Committees. The theory of the wandering of the channel, being the remedial measure that nature had adopted for maintaining the capacity of the estuary, appeared to him to be then incontestably proved, and nothing he had since heard had changed that opinion. No doubt the body of water in the Crosby Channel, outside the Rock Lighthouse, also played a most important part in maintaining the sea channels across the banks; but he need scarcely point out that the Crosby Channel itself had to be maintained, and he failed to see how its maintenance would be secured if there were no upper estuary to act as a reservoir for sluicing water. He had listened with great interest to the remarks of several speakers on the subject of the bar of the River Mersey. All were agreed that the bar constituted a very serious obstruction to the trade of the port, and he did not wish to question the fact; but at the same time he would like to point out that there were circumstances in the case which prevented the obstruction being intolerable. For several hours in each twelve there was water over the bar for vessels of the deepest draught, and even if vessels could cross the bar at any state of the tide, they could not enter the docks except at or near high-water. The chief legitimate causes of complaint, therefore, were that the detention to inward-bound vessels outside the bar somewhat imperilled their safety, and, in the case of slow vessels, might cause them to miss their chance of docking. The most weighty grievance was the detention of passengers on board the great liners, and the inconvenience caused to them through having to be transferred to tenders instead of proceeding to a stage to disembark. The Mersey Docks and Harbour Board was fully aware of the neces-

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Mr. Lyster. sities of the case, and of the force of the calls made for improvement, and was also, perhaps, better able than many others to appreciate the physical and financial difficulties to which he had referred as surrounding the question. At present, as would be understood, he was not in a position to discuss fully and freely the several interesting points as to training-walls and other such remedial expedients, and he would have merely to say that the Board had quite recently decided to try an experiment in dredging, no doubt in some degree moved thereto by the fact that a measure of success had attended certain dredging operations in New York, with which port the shipping interests of Liverpool had a close connection. Personally, he was not to be considered as of opinion that the sand-pumping experiment would approach the results which some people expected from it; but it would give an amount of experience which would be interesting, and not without its uses in connection with the study of the general question of the amelioration of the sea channels of the Mersey. He could not now speak as to what works ought ultimately to be undertaken, nor as to the manner in which the cost of those works should be defrayed.

Correspondence.

Mr. Carr. Mr. R. Carr enquired the cost of the sluicing appliances laid down at the Canada Basin, so that it might be compared with that of other systems of keeping dock-entrances clear from sand or mud silting. In addition to first outlay, what was the cost of maintenance, and was there any special cost for labour whilst sluicing? It might be that this was done by the men employed in locking vessels, in and out, as part of their ordinary daily duty. And what was the effect within the Langton Dock, which was drawn down about two hours every tide, with the double purpose of sluicing the entrance and meeting the rising tide, to make a level? Did the volume of flood-water, brought in by the tide, leave a deposit of silt that had to be taken out; if so, what cost did it involve, and how was the silt removed? At the Tilbury Docks on the Thames, there was a tidal basin, bearing a close resemblance to the Canada Basin, with a wide entrance, open to the tide at all times. It was 19 acres in area, and, when first opened, it cost a large sum annually to maintain a depth of 26 feet below low-water level by the bucket-ladder system of dredging, and depositing the mud on the land. At present it was kept clear to that depth by an invention of Mr. Tydeman, one of the West India Dock staff.

This was a tug-boat fitted with American pumps, that discharged high-pressure water through jets, in suspended pipes, close to the surface of the mud, which was stirred up as the steamer moved about the basin, and went out with the ebb-tide, about five hours in every tide. This was effected at a cost, including all labour, stores, repairs, depreciation, and interest on capital, of £1,680 per annum. Another thing would be interesting to know, whether the lock gates at the Liverpool Docks were of greenheart, or whether the more modern fashion of iron and steel had been adopted. Mr. Carr.

Mr. W. Dyce Cay observed that he had been engaged for thirteen years, up to the beginning of 1880, in designing and carrying out works for the lowering of the bar at Aberdeen. His opinion, as to the cause of the formation of the submarine ridge of sand at the harbour mouth called the bar, was that it was occasioned by the sudden breaking of the waves, travelling shorewards, owing to the constriction of the channel at the entrance, and the opposition to them there of the outward river and tidal flow; the bar, once begun, aided in breaking the waves, and formed, as it were, a shelter for the deposition of the sand they carried. The works under his superintendence widened, deepened, and regulated the channel, and removed old constricting works, while extending new piers seawards; and the effect had been to increase the depth about 2 feet, while adding greatly to the width and navigating room of the entrance. He thought that this principle, of forming a channel gradually widening and deepening as it entered the sea, would be found to have a pretty general application, though necessarily each case must be judged on its own circumstances, and to have an analogy in those natural estuaries where there were no bars. He was glad the function of the river water of the Mersey estuary had been so distinctly described by the Author, namely that it maintained the tidal receptacle by scouring it at low-water, while the receptacle, on its part, maintained the navigation and sea-channels by the flow and reflux of tidal water into and from it; for there were many harbours, with rivers flowing into them, where the river had no function to fulfil, and was a source of great disadvantage and expense, owing to the silt brought down and the dangers to navigation it caused when in flood. In such cases, where possible, it would be better to divert it out of the harbour. With regard to the durability of Portland cement in sea-water, he thought that, as in the case of hydraulic limes, one sample of Portland cement, manufactured of chalk and clay, got from one place, might be more durable than another sample made from materials obtained in a different place; Mr. Cay.

Mr. Cay. also that one kind might be suitable for one place, but not for another. Some simple test of durability was a desideratum; meanwhile, manufacturers might indicate to users where their cement had stood a sufficiently long trial. No doubt all lime compounds, including cements, were liable to injury more or less from the action of the salts contained in sea-water; but as there were no other cementing materials, all that could be done was to use those least liable to damage, and in the most efficacious manner. The cause of this injury was well described by Vicat upwards of thirty years ago; he said:[1] "Si l'on verse de l'eau de chaux dans de l'eau de mer, il s'y forme sur-le-champ du sulfate et du chlorhydrate de chaux, et il se précipite de la magnésie rendue libre;" he further stated that the affinity of sulphuric and hydrochloric acids for lime was not only sufficiently powerful to produce these effects, but even to detach this base from its combinations with silica and alumina. Vicat made experiments on the durability of lime compounds and cements in sea-water, by immersing them in a very dilute solution of magnesium sulphate, namely, 4 to 5 grams of anhydrous salt, or 8 to 9 grams of the same with its water of crystallization, dissolved in 1,000 grams of pure water. The mortar or cement to be tested was first allowed to set for a month or more in a hermetically-closed glass vessel; this was then broken from the specimen, and the cement was immersed in the solution, which was renewed as often as the test with ammonium oxalate showed the magnesia solution to be charged with sulphate of lime. Those specimens, apparently intact after ten months of this treatment, he cut into two or three pieces, and if sound in the interior, he again subjected them to the magnesia bath; and; if they stood for five or six months intact, he held them to be indestructible in the open sea. He said that if kept for ten months more, or in all twenty months' immersion, the best mortars, such as that of Teil lime, which had stood for ten years intact in the blocks at Marseilles and Port Vendre, showed slight signs of alteration; but for all that it was good for sea-work. Some of the results of these experiments were that the greater number of mortars succumbed to them; natural hydraulic limes containing five or six times more silica than alumina alone resisted. Few cements did so. Some cements were improved by heavy burning so as to resist change completely for seven or eight months, and were not much damaged after two years, which might give time for a crust

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[1] Traité pratique et théorique de la composition des mortiers, ciments et gangues à pouzzolanes, &c.; par L. J. Vicat, p. 79, Grenoble, 1856.

Mr. Cay. to be formed by the sea. Vicat also found, as to the composition of the cements of commerce, relatively to their durability in the sea—1st, That there was no relation between the durability and the hardness. 2nd, Independently of the composition of the clay in silica, alumina and magnesia (if any), the chance of stability was so much the greater as the sum of these three substances was nearer equal the amount of the lime in the cement, and taking the latter at unity, 0·80 was the limit below which the quantity of clay, iron not included, ought never to be; it followed, he said, that cements charged with lime, whatever the degree of calcination, were not suitable for sea-works. This appeared to point to Roman cement, the analysis of which, as given by Mr. George R. Burnell,[1] was for the Sheppey stone, 55 lime, 38 clay and 7 iron, and as analyzed chemically by Berthier—

Carbonate of lime	0·690 = (say)	Lime	0·380
		Carbon dioxide	0·310
		Total	0·690
Magnesia	0·002		
Oxide of iron	0·037		
" manganese	0·012		
Silica	0·180		
Alumina	0·066		
Water	0·013		
	1·000		

If, however, the use of Roman cement only was obligatory, evidently the construction of sea-works would be much restricted; but Mr. Vicat approved of the hydraulic lime of Teil in Ardèche, France, for works in the Mediterranean. This lime, besides being used in the works mentioned above, was adopted for the Port Said works and those at Trieste. Its analysis had been given by Mr. F. Bōmches.[2] There the lime was to the soluble silica, alumina, and magnesia, as 1 to 0·28; while Vicat supplied an analysis of the waters of the Mediterranean, the Atlantic, and the English Channel,[3] from which it would appear that the destructive salts were in greater quantity in the Mediterranean than in the Atlantic, and that the lime of Teil had a less proportion of soluble silica and alumina than English Portland cement, the averages of the consti-

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[1] "Rudimentary Treatise on Limes, Cements, Mortars, &c.," by George R. Burnell, 8th edition, 1869, p. 58.

[2] Minutes of Proceedings Inst. C.E., vol. lxii. p. 209.

[3] Traité pratique et théorique de la composition des mortiers, ciments et gangues à pouzzolanes, &c.; par L. J. Vicat, p. 78.

Mr. Cay. tuents of five qualities of which, given by the late Mr. John Grant,[1] were:—

Lime.	Silica.	Alumina.	Oxide of Iron.	Magnesia.	Sulphuric Acid.	Potash Soda.	Carbonic Acid Water.	Insoluble residue.
59·23	21·87	6·61	5·86	0·73	1·31	1·48	1·00	1·29

The lime of Teil was, however, used in strong and impermeable proportions; from the figures given by Mr. F. Bömches about 1 part of lime to 2½ parts of sand.

The experiments of Messrs. L. Durand Claye, and Paul Debray,[2] showed that sea-water, filtered under pressure through permeable Portland cement mortar, had a destructive effect; their conclusion that the dislocating effect was caused by the crystallization of sulphate of lime, formed by the action of the sea-water salts on the lime, was not new, it having been previously mentioned by Mr. G. R. Burnell,[3] as having taken place in the mortars used at Fort Boyard. Their experiments, demonstrating what proportion of water made the most dense and least permeable concrete, were valuable. Engineers would naturally, if they had not before done so, take precautions against filtration under pressure of sea-water through cement mortar or other lime compound, and though nothing very distinct had yet been brought out as to the constitution of the Portland cement, most durable in sea-water, it would appear that any disturbance of the molecules of cement by excess of water in gauging, or by passing loose through water in deposit, so as to separate the lime from the silica, would render it more liable to attack by the chemical salts contained in sea-water. He had found that excellent Portland cement was supplied to a specification based on Mr. Grant's researches, namely, 90 per cent. to pass through a sieve having 5,800 meshes per square inch, and sample briquettes made of 1 part sifted cement, 3 parts standard sand, and 10 per cent. water, kept one day in air, and twenty-seven days in water, to bear a tensile-strain of 200 lbs. per square inch. The addition of a seven-day test to ascertain the rapidity of setting, the "hardening energy" mentioned by Dr. Michaëlis,[4] would be an improvement, as quickness of setting was an additional protection against the sea-salts.

Mr. Crawford. Mr. ROBERT CRAWFORD, of Greenock, observed that on the 20th of June, 1882, Mr. Kinipple submitted a report on proposed jetties,

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[1] Minutes of Proceedings Inst. C.E., vol. lxii. p. 130.

[2] Annales des ponts et chaussées, 6e série, tome xv., 1888, p. 816; and Minutes of Proceedings Inst. C.E., vol. xcvii. p. 445.

[3] "Rudimentary Treatise on Limes, Cements, Mortars, &c.," by George R. Burnell, 8th edition, 1869, p. 58.

[4] Minutes of Proceedings Inst. C.E., vol. lxii. p. 232.

Mr. Crawford.

sheds, and travelling cranes, for the Albert Harbour, Greenock. The plans accompanying it showed the jetties and a cross-section of the sheds with the cranes on the roof. The travelling cranes designed and superintended by Mr. Kinipple for the James Watt Dock had proved the most serviceable cranes at the Greenock Docks, running as they did along the verandah in front of the sheds and warehouses, and of sufficient height and width to allow two lines of railway wagons to pass under them. He had carefully gone into the question of harbour cranes lately, and could safely assert that the overhead cranes proposed by Mr. Kinipple for the Albert Harbour in June, 1882, and the cranes erected by him at the James Watt Dock, were the most suitable type of crane for general purposes at the Greenock Docks. He was at present designing a 30-ton steam crane, to be erected on a travelling gauntry of sufficient height and width to allow two lines of wagons to pass under it. This crane was intended to work on a jetty where there were no sheds nor warehouses.

Mr. Cunningham.

Mr. D. CUNNINGHAM remarked that the West Tidal Harbour of the Port of Dundee, in the River Tay, occupied a position in the estuary somewhat similar to that of the Canada Basin at Liverpool to the estuary of the Mersey, though the Canada Basin was relatively nearer the sea. The silting within such a basin was naturally considerable, more particularly when depths suitable for modern sea-going vessels had to be maintained. The West Tidal Harbour at Dundee formed the vestibule to the older or shallow docks. The amount of dredging required, up to twenty years ago, to keep it in a serviceable condition for the passage of vessels of comparatively light draught, was 45,569 tons per annum. For the last eight years it had been 29,575 tons, or less than two-thirds the former amount. This improvement had not been caused by the introduction of additional sluices, such as those constructed for the Canada Basin, but by the removal by dredging of a large sandbank which lay in the river opposite the entrance. The effect of this sandbank was to cause the ebb-tide water to flow into the harbour on the surface; it made the circuit of the walls and passed out again below the incoming current, in its course always depositing considerable quantities of mud. The construction of such culverts and sluices as those described was most desirable in such situations, and the very creditable example of Liverpool would, no doubt be followed with much advantage whenever it could be carried out. The estuary of the Mersey was somewhat similar in shape and circumstance to the estuary of the Tay. But while the tidal water, which passed up the estuary of the Mersey, par-

Mr. Cunningham. ticularly at high spring-tides, was a good deal more than what passed up the Tay above Tayport, the position of which was similar to that of New Brighton, the fresh river water passing down the Tay was upon an average about three times that of the Mersey. The ebb-current therefore became, in relation to the flood in the Tay, stronger than it was in the Mersey, and hence the improved scouring effect manifest in the former. For instance, the highest points of the sands stretching across the mouth of the River Tay, where vessels entered, ranged between 18 and 23 feet below lowest low-water of spring-tides, whereas the navigating depth over the bar at lowest low-water of spring-tides in the Mersey was only 10 feet. There were also no practicable by-channels in the Tay. It was manifest that, with an improved scour on the ebb, the condition of the lower channel of the Mersey would approximate to that of the Tay. Large and costly works had been, from time to time, proposed for this purpose, and it was considered that the attainment of the desired end was surrounded with physical and financial difficulties of no ordinary character. He scarcely agreed with this manner of viewing the question, for his experience upon the River Tay led him to conclude that the satisfactory deepening of the bar of the Mersey would be by no means such a very difficult, costly, or hazardous operation. Three years ago it was resolved to widen the navigable channel of the River Tay, some 3 miles below Dundee, where it was about 500 yards across (between the 18 feet below low-water contour lines), but at a bend where vessels coming up experienced some difficulty in clearing the north shore. The Newcome spit, projecting from the southern shore, and thus restricting the channel, consisted of a vast mass of clean and perfectly free coarse sand. The ordinary ladder dredger employed at the harbour was stripped of its buckets, and a longitudinal propeller-shaft with propeller, fixed upon the ladder instead, by means of which a strong current was produced at the time of ebb-tide when the lower end of the ladder was lowered to the surface of the sands. In three months, at a very moderate cost, the point of this spit was so much lowered, as to enable the buoy defining the south side to be shifted in position 500 feet to the south-west, the channel having thus been satisfactorily widened. Such an effect might be produced on the bar of the Mersey, at a moderate cost, by the employment of one of the large ocean-going steamers ballasted aft, and moored so as to bring the power of the engines to the fullest practicable extent on the moving sands which constituted the bar. The effect of such action would be to immediately lower the bar at the point attacked.

Mr. Cunningham.

There having been thus produced a freer passage for the flood and ebb waters over the bar, the minor side channels would rapidly close up, particularly if such work were carried out in winter when the weather was unsettled. Once such channels became partially closed, and in the degree in which they became so, the improvement carried out in deepening the bar would tend to become permanent. In such simple and economical manner he was sure that, without the execution of any sea-works, the present depths on the bar might be much improved.

Mr. Findlay.

Mr. G. FINDLAY pointed out what, in his opinion, was a considerable drawback to the efficiency of the dock arrangements at Liverpool. The railway facilities should be in many respects greater, and should include convenient access for railway wagons to and from the berths and quays; and the unloading of vessels, instead of being mainly dependent on the ship's gear and tackle, should be provided for by hydraulic cranes, such as existed at the docks in London and at most of the other important docks, as, for instance, Hull and Cardiff. He thought no great system of docks, such as the Liverpool Docks, could be considered complete in the absence of appliances such as he had mentioned.

Mr. Mann.

Mr. L. J. MANN remarked that the tendency of the bar to move seaward would, no doubt, as in the majority of similar cases, be considered as unfavourable; on the other hand, as its position became less sheltered by the land, it would become more exposed to the action of large waves, which would have a decided tendency to prevent undue accretion. In the year 1867, the depth over the bar at low-water of spring-tides was 12 feet;[1] and in the present Paper it was given as 10 feet at low-water springs. The depth, therefore, seemed to have decreased by 2 feet in twenty-two years; if this was so, it would be interesting to know whether this diminution of depth was regular, or fluctuating, and whether the present tendency of the bar was to increase or otherwise. The greater size and draught of ocean steamships, and the element of time becoming so important, naturally rendered the impediment of a bar additionally formidable. With regard to the datum to which all levels in the Mersey were referred, it was usual at other ports to adopt as a datum a standard low-water of equinoctial, or other tides, and although a standard tide at Liverpool seemed to be taken as rising 21 feet above, and falling 10 feet below the Old Dock Sill, it seemed peculiar that the low-water of that tide was not adopted without the intervention of an intermediate datum. With regard to

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[1] Minutes of Proceedings Inst. C.E., vol. xxvi. p. 425.

Mr. Mann. the dock accommodation, every increase of trade had been promptly met, but not overdone, by providing larger and deeper docks, and greater storage room. The Author had not entered into the details of dock construction; considerable variation was, however, noticeable in the batter given to the faces of the walls of different docks, the reason for the variation not being apparent. Mr. Mann's experience had led him to the conclusion that a batter of 1 in 12 fulfilled all the requirements of vessels lying alongside, and in addition enabled the centre of pressure on the foundations to be kept near the centre of the structure. In view of some comparatively recent failures of Portland cement concrete exposed to the action of sea-water, it was satisfactory to find that although very large quantities of that material were used by the Author, during a long period of years, he had not had to record any instance of failure, but the reverse.

Mr. McConnochie. Mr. J. A. McConnochie observed that the Author stated, that "men of energy and enterprise" and "pioneers of progress" of Liverpool "had the honour of devising and constructing the first wet-dock built in England." This was a mistake, as the first wet-dock in England was undoubtedly the still existing Greenland Dock of the Surrey Commercial Dock Company at Rotherhithe, originally called the Howland Great Wet-Dock. The honour therefore belonged to the Thames, and singularly enough was due to the enterprise of a lady, Mrs. Elizabeth Howland, widow of John Howland, of Streatham, whose daughter and heiress married, in 1695, Wriothesley Russell, Marquis of Tavistock, who afterwards became second Duke of Bedford. The dock and adjoining property passed to the Bedford family under this marriage settlement, and continued in their possession till 1763, when they were sold to John and William Wells, and after passing into other hands were purchased by the Commercial Dock Company in 1807. The Act for constructing a wet-dock at Liverpool received the Royal assent on the 24th of March, 1709. The Act for constructing a wet-dock at Rotherhithe received the Royal assent on the 10th of April, 1696. The short title of the latter was "An Act to enable trustees to raise money for the making a wet-dock and improving the estate of the Marquis and Marchioness of Tavistock at Rotherhithe, in the county of Surrey." The Act recited that the Marquis and Marchioness were both minors, and that the said Elizabeth Howland, widow, had advanced and lent £2,500, which had been laid out in a considerable improvement made upon part of the lands adjoining to the River Thames, by making a dry-dock for the benefit of shipping, and that the residue of the said lands

Mr. McConnochie.

was capable likewise of being greatly improved, by laying out a further sum of money, which they had computed might amount to the sum of £12,000, in making a wet-dock there for the benefit of shipping. Certain lands were mortgaged to raise the money, and the dock was proceeded with; a second graving-dock was also added, and Mrs. Elizabeth Howland appeared to have purchased them in 1703, and paid off the mortgage. The date of the opening of the dock was not recorded, but it was in use in 1703 as appeared from the following description, which was printed, with an old engraving of the dock, retained in the Board room of the Surrey Commercial Dock Company.[1] The docks and works at Liverpool,

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[1] HOWLAND GREAT WET-DOCK,

In the Parish of Rotherhithe, or Redriff, belonging to Mrs. Howland, of Streatham.

This dock hath been found a very safe repository for ships, which was fully proved in that terrible and violent storm which happened on the 27th November, 1703, when by the extremity of the wind all the ships in the river, which rode either at chains or their own moorings, were forc'd adrift, and confusedly driven on the north shore, where some were left, and most received great damage. Then, of all the several ships deposited in this wet dock, there was only one injur'd, and she only in her bowsprit, which was in a great measure imputed to too secure a negligence in the persons who moor'd her there. This may remain a lasting evidence of the great service such a repository for shipping is to our navigation; especially if it be consider'd that this fatal storm happen'd soon after the planting of those trees, which are on the south and north as a fence to the dock from winds, and which are now grown to a considerable bulk; and also before that range of houses were built to the west, and the pailings set up to the east, and on each side; so that now, in the hardest gales of wind that have within these late years happened, notwithstanding the large extent of the water, the wind does not give any such motion to it, as can endanger the smallest boat in passing it any way over, and tho' very deep loaded. And as ships are here so well secur'd from any storm that may happen, so they are entirely defended from the hazard and damage which accrueth to them often in the river, by hard frosts. For by the driving of the ice in the river, if they should continue in the stream on float, their cables would be cut; to prevent which, and to preserve their bottom, they are forc'd to take up with shore births, which often are straining and uneasy to the ships, and require a constant care and charge to preserve them, by shoring or shifting, as it may happen, by the ice's driving under them. And notwithstanding all the care which can be taken, the bottoms of ships are so raked by the ice, that it is often a considerable addition in the charge of refitting, if no other more material damage happens to them thereby. Whereas the ships here deposited, lye always waterborne, without the least rubbing of the ice, or any farther care or charge for their preservation, as fully appear'd by the last great frost in 1715. Ships are likewise here more effectually secur'd from the peril of fire; there being proper cook-rooms provided on shore, and no fire suffer'd to be on board. But if neither storms, nor ice, nor fire, be consider'd, ships are here deposited at a much less charge and a much greater security than in the river; which any one may easily

Mr. McConnochie. described in the Paper, were undoubtedly unrivalled, both as regarded the care bestowed on the designs, and the substantial manner in which they had been executed. They were an example of what the works of a public trust ought to be. Many engineers, however, were compelled, by the exigencies of providing dividends for shareholders, to proceed on less satisfactory, if more economical, lines. The narrow width of quay, between the sheds and the docks, at Liverpool, always appeared to him inconvenient, and had necessitated the design of the crane travelling on the roof of the sheds. This crane, for the rapid working now demanded in the steam-shipping trade, was, in his opinion, from its elevation, inferior to the ordinary crane travelling on the quay, as the greater length of chain, between the jib head and the load, when being swung, imparted a motion to the load which entailed loss of time in steadying. This, perhaps, accounted for the somewhat slow rate of working stated in the Paper, 80 lifts per hour being common with the quay cranes at the Surrey Commercial Docks.

Mr. Redman. Mr. J. B. Redman observed that Liverpool had for nearly two centuries been the rival and compeer of the Port of London, over

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evince, if he will calculate the wearing their cables or the charge of the chain, the frequent shifting of the moorings, and other necessary incidents, which do and will happen in the river, and compare them with the moderate rates wet-docking is by this work reduc'd to.

Description of the Dock.

The outward gates of the wet-dock, leading to the Thames, 21 foot high, and 44 foot wide, open'd to let in the ship.

The bason, or gut, leading to the great wet-dock, 44 foot wide, 150 foot long.

The inward gates, of the same height and breadth with the outward, but stronger, by reason they bear the great weight of water in the dock, which sometimes flows within a foot of the top of these gates, and is kept pent up within four foot thereof.

The great wet-dock, wherein at good spring tides there is seventeen foot of water, over the cell against which the bottom of the gates shut; so that it would commodiously receive his Majesty's third-rate ships.

The dimensions of the dock are from east to west 1,070 feet; from north to south, at the west end, 450 feet, and from north to south, at the east end, 500 feet; so that it would contain upwards of 120 sail of the largest merchant ships, without the trouble of shifting, mooring, or unmooring any in the dock, for taking in or out any other.

This dock when full at a spring tide, contains, by a moderate computation of 40 foot solid to the ton, 228,712 tons of water, being much larger than the famous bason of Dunkirk, or any pent water in the world.

The mast crain, for taking out and setting in masts in ships in the wet-dock, which answers the end of an hulk, with proper pits and crab for careening three or four ships at once.

Mr. Redman.

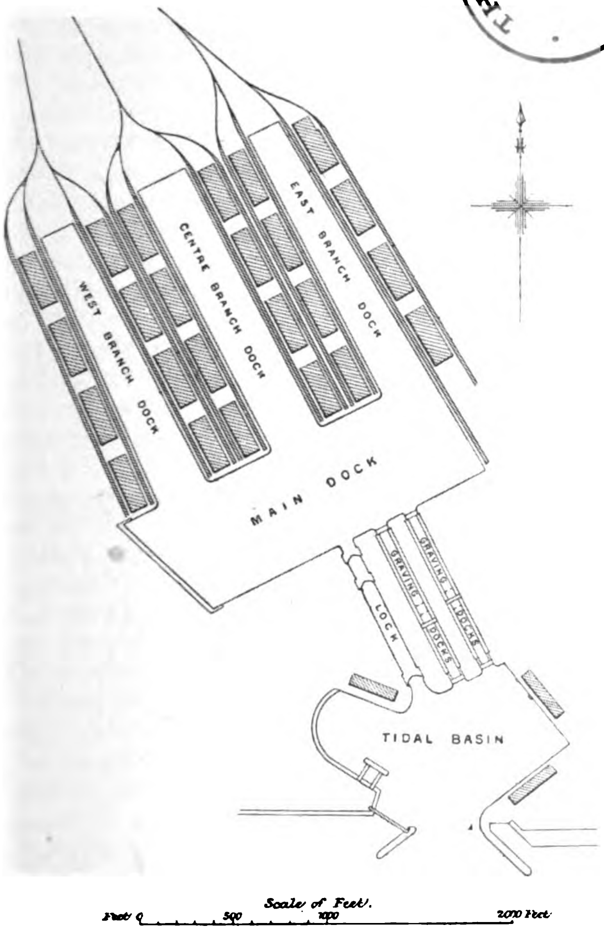
which it possessed certain physical advantages, namely, greater proximity to the seat of manufactures, and to the ocean; and a somewhat loftier oscillation of tide—27 feet as compared with 20 feet. But, on the other hand, the minimum depth of the ocean approach was only one-half that of London—10 feet as compared with 20 feet—so that high-water depth was less by 3 feet—37 feet as compared with 40 feet. However, to blame the Mersey Docks and Harbour Board without reservation, for a state of things inherent from the physical conditions of the estuary, would be hypercritical; for Liverpool was by no means alone in having an outer threshold carrying much less water than the sills of its deep-water docks. Three Royal Dockyards and two commercial depots might be selected in illustration. Portsmouth Dockyard, on which vast sums of money had been expended for extension works, could command 7 fathoms immediately into the harbour; but to enter or leave this anchorage a low-water channel, 2 miles long, very narrow and carrying only 20 feet at low-water, must be navigated; so that practically this depot could only be approached by large vessels at or near high-water. The same applied to Chatham and Sheerness, and to the Port of Victoria, the South Eastern Railway Station, the entrance to either of which was gauged by shallows below the Nore carrying only 20 feet. Again, the Tilbury Docks were in the same predicament; commanding as they did an ample depth of water in Gravesend and Northfleet reaches, the approaches were gauged by shallows in the lower part of Gravesend and Sea reaches, and below the Nore carrying only 20 feet at low-water spring-tides. The new eastern channel into the Black Deeps off the North Foreland, called in Macartney's and other charts of the last century, "Fisherman's Gatway," and then carrying 40 feet for half its length north, and 20 feet for the rest southward, was found to have 40 feet throughout by Captain Bullock, R.N., in his surveys of the Downs and approaches to the Thames, fifty years ago, and was afterwards called Bullock's Channel. Subsequently, when buoyed, and now recently lighted, it had been called the Duke of Edinburgh Channel, in compliment to the present Master of Trinity House. A detour of several miles was involved in the use of this channel, and most vessels would continue to use the Alexandra channel to the westward, except heavily draughted ships arriving at dead low-water, as it only commanded a minimum depth of 20 feet, and several large ocean steamers had taken the ground there, from this circumstance. As regarded the removal of the bar at Liverpool, the question was so large, and involved so many considerations, that it would be rash in a discussion like this to advance very

Mr. Redman. specific opinions. The Mersey estuary, like that of the Seine, was circumstanced to receive and retain the highly flocculent and shifting sands heaped up in either, and any one who had slept a night in New Brighton, during a gale of wind could well appreciate this, for it was difficult in the morning to get abroad, due to heavy drift of the light flocculent sand over the thresholds. To remove the Mersey bar meant dredging down for 20 feet, which, unaccompanied by other measures, would somewhat resemble the labour of Sisyphus; to erect guiding-banks on the crests of the outlying, partially submerged sands would, to say the least, be a game of speculation, and a very costly one. Groynes run out over the forelands, to be subsequently connected near their extremities as their effect was developed, might do much in directing the ebb current against the bar; but any method would demand a long course of study of the various charts as far back as printed, as well as of the progressive stages of tidal storage in the estuary. A naval friend, years back, who was well acquainted with Liverpool, repeatedly urged on his attention the connecting of the Mersey and Dee estuaries by a tidal cut, as affording a second deeper and less encumbered entrance; and this idea has been put forward recently in other quarters. The same remark applied here, that before seriously entertaining such a project the progressive stages of these estuaries must be studied, by a comparison of early and modern charts. Those estuaries, like that of the Seine, appeared specially planned by Nature for the reception and retention of their easily moved, light drifting sands. As regarded the arrangement of the Liverpool Docks, an interesting feature of dock construction was well illustrated. In the early metropolitan and provincial docks, a large area was required for the swinging of sailing ships, and the quay value compared to the area enclosed was a low one. This value had been raised in later years by running out jetties into the docks, and this, to a certain extent, temporary measure had become a recognized feature in the planning of modern docks, brought about by the inner recessed portions of the area subdivided by permanent projecting piers of similar construction as the rest of the margin. Again, a lower area compared to the tonnage accommodated, was now necessary from the fact that a large steamer of the present day, of from 5,000 to 6,000 tons burthen, might be said to represent five 1,200-ton East Indiamen of yesterday, and whilst making double the number of voyages per annum performed by its predecessor, would occupy berthage in a dock for days as compared with weeks formerly; so that it was really no mere figure of speech to say that one of these large steamers, as regarded work done, represented a fleet of ten East Indiamen of the past. Mr. Redman. Another feature of practice was illustrated by these works. Mr. Jesse Hartley was, like his compeers, most exact and careful in the execution of the ashlar masonry of the quay walls; in his later days he revolutionized his practice by adopting cyclopean masonry in random courses, and this again had been shelved by modern hydraulic concrete in mass, no doubt affording great facility of execution and reduction of cost; but these walls did not bear comparison with earlier works, at least in the Port of London, and they bore on their face a more battered, ruinous appearance than the ashlar walls of the early part of the century. Doubtless in the future this material for such works would be generally measured, mixed, and applied by machinery. The trade of the United Kingdom had so wonderfully increased, the figures, while appealing powerfully to the imagination, were so extraordinary, that he hesitated to quote them; but the Board of Trade Returns appeared to show that the aggregate amount for last year was represented by £680,000,000 sterling, and that the increase over the year before last amounted to £1,000,000 sterling per week, or £52,000,000, or one-seventh of the whole, the largest amount ever received; and possibly the result was greater than in any commercial community during the world's existence. This showed plainly enough that there was ample field for such works, and this record of the Liverpool Docks would prove an invaluable guide to those planning or superintending them.

Mr. Scott. Mr. JESSE F. SCOTT considered there was much in the dock system of Liverpool of peculiar interest to those acquainted with the development of the dock systems of the Port of London. Both the Thames and Mersey (and some other ports in the front rank nearly half a century ago) were burdened with a great area of antiquated docks which were practically valueless. They were constructed at a greater relative expense than the docks of recent years, and in many cases upon very costly sites. These old docks could not now be utilized for vessels of modern dimensions, and in some instances it was doubtful whether the small trade they at present accommodated paid for their proper maintenance, to say nothing of interest upon the capital invested in them. The attempt at Liverpool to utilize some of these old docks, by connecting them with modern entrances and artificially raising their original water-level, so as to adapt them for ships of moderate draught, was an experiment that would be watched with interest, as offering at least a partial solution to what was felt to be a difficult problem. The depth of water upon the sills of the newer Mersey Docks was small

Mr. Scott. compared to what was usual on the Thames. The deepest sills at Liverpool and Birkenhead had but 23 feet 7 inches of water over them at high-water of average neap-tides, with occasionally some 3 feet less. It was apparent that for several days in each fortnight first-class vessels entering the port could not at neap-tides proceed to the berths in the docks, until part of the cargo had been discharged overside into lighters whilst in the tideway, the same difficulty being experienced with outward-bound vessels which must either await a suitable tide to leave the docks, or complete their loading in the river. On the Thames there were nine lock entrances having a greater depth of water at neap-tides than any on the Mersey; and, owing to this greater depth, it was never necessary in the Port of London, to discharge any portion of the ship's cargo before entering the docks, and outward-bound vessels could leave the docks and proceed at once to sea at any high-water. The two largest dock entrances on the Thames were the new entrance to the Royal Albert Docks, and the lock at Tilbury. Both these locks were 80 feet wide and had three pairs of gates. The length between the inner and outer gates was in the first case 555 feet, and in the latter case 700 feet. The depth of water on the sill at high-water of neap-tides was about 30 feet at the Royal Albert Docks, and about 39 feet at Tilbury Docks, being respectively about 6 feet 6 inches and 15 feet 6 inches deeper than the best entrances at Liverpool and Birkenhead. The depth of water at Tilbury Docks allowed a ship drawing 23 feet to be docked at the moment of arrival at low-water of spring-tides, and even in the case of ships of greater draught the delay need never exceed an hour or so, the ship in the meanwhile being accommodated in the tidal basin where facilities were provided for landing passengers and their baggage. This was a striking contrast to the state of affairs at Liverpool, where the whole of the docks were practically closed against fully-laden first-class ships for several days at frequent intervals. The system of branch docks at Liverpool, gave the maximum of quayage with the minimum of water area; it brought the whole of the business within a reasonable compass for working purposes, and it lent itself to a convenient system of railway communication, provided there was sufficient land space at command at the heads of the branch docks. This arrangement had been carried out at Tilbury Docks, where the system had reached its highest present development (*Fig. 3*). At Tilbury Docks it had been found possible to provide quay berths in the three branch docks for twenty-four ships of an average length of 400 feet, in an aggregate water area of but 29½ acres; with direct railway communication to each berth without the use of turn-tables, or any curves less than 6 chains radius. The main dock, of 23 acres water area, served for turning the vessels as required, and could accommodate five first-class ships besides smaller craft at quay berths along its sides. In Mr. Scott.

Fig. 3.



TILBURY DOCKS. ARRANGEMENT OF BRANCH DOCKS.

regard to the relative amount of trade, and dock charges at Liverpool and London, it should be borne in mind, that at Liverpool, the Harbour Board, with slight exceptions, merely provided dock accommodation for the ship. On the Thames, it was customary for

Mr. Scott. the Dock Companies not only to provide this dock accommodation, but also to unload the ship, and warehouse on their own premises a large portion of the goods, often for a considerable period of time, besides doing much else for the convenience of the traders. Any comparison of the dock charges must therefore be fallacious, unless these important differences of services rendered were taken into account.

Mr. Strype. Mr. G. W. STRYPE said that the extraordinary number of vessels that could be passed inwards and outwards, during such a very short time upon each tide at the Liverpool Docks, deserved notice. The advantage of lowering the sills of the docks was very great, and its successful results were marked. These appeared to be chiefly due, and dependent upon, the ingenious method by which the surplus water inside the docks was employed, to disturb and scour away at suitable times the sediment that would otherwise be deposited. The adoption of large cast-iron mains in connection with the sluices had many obvious advantages. The chief drawback of the cast-iron was its perishable character, due to the oxidation of the surface exposed to the corrosive action of salt water, but this surface had been protected by a coating of Portland cement of only some $\frac{3}{4}$ inch in thickness, secured by means of ribs cast with the pipes upon the inside. It would be interesting to know how the cement was applied, and whether it was liable to cracking away in flakes from the inside. Several unsuccessful experiments had been made to coat the inside of large cast-iron pipes, to prevent their gradual destruction from oxidation, by means of enamelling; but if so thin a layer as $\frac{3}{4}$ inch thick of Portland cement when properly applied would answer the purpose, and found to be reliable as in this case, it was clearly a most valuable method of preservation to employ. It would also be of interest to know whether any difficulty had arisen by the pipes themselves becoming fouled with silt, and requiring to be cleansed, from time to time by other means than that of the scour of the water passing through them.

Mr. Stoney. Mr. BINDON B. STONEY observed that a few months ago, while inspecting several of the works described in the Paper, he was especially struck with the facility with which large steamers passed out of the Langton Dock by one entrance, while a fleet of small river craft entered through the other. The direction of the opening into the Mersey, contrary to what might perhaps at first suggest itself, answered admirably to facilitate the ingress and egress of shipping, and at the same time it sheltered the lock-gates from the influence of storms. The principal ports of the United

Kingdom might be broadly divided into two classes, namely, those situated on sheltered tidal rivers with a moderate range of tide, such as Dublin, Belfast, and Glasgow, in which floating docks were the exception, as most of their trade was conducted along open river-quays, and ports like Liverpool and Hull, in which, on account of the great range of tide and the exposed character of the river, floating docks were essential. Ports with large tidal range had the advantage that the foundations of their dock walls were seldom laid much below low-water, whereas river quays had frequently to be founded at from 20 to 30 feet below low-water, in order to permit large vessels to lie afloat at all states of tide. On the other hand, river-quays were generally available for every foot of their length, whereas docks had locks and gates, waste corners, and often tidal basins, the cost and working expenses and maintenance of which had to be supported by the revenue derived from the quay space inside. River-quays also permitted vessels to enter or leave their berths with great dispatch, and when, as in Dublin, the depth in the river and on the bar was sufficiently great, cross-channel steamers could sail at fixed hours irrespective of tide. This latter was a matter of great importance for this class of trade. On a survey of the older docks in Liverpool, it would probably strike most observers that they were small and numerous and that the size and cost of their approaches, locks, gates and waste bits of quay, were large compared with the available quay space within the docks; and the corresponding staff to manipulate these numerous entrances seemed also great in proportion to the useful accommodation within. This faulty characteristic of the older docks had evidently not escaped the Author in designing the new works, and, in the increasing competition between various ports, engineers should study economy, not only in the first cost, but also in working expenses. On comparing the revenues of Dublin with those of other large ports in the United Kingdom, Mr. Stoney was often filled with envy at the large sums available for new works elsewhere. In Liverpool, for example, the Author stated that the revenue derived from 9,292,000 register tons was £990,500, or on an average 25·58*d.* per ton register. This, owing to the recent reduction of rates, was much less than it was a few years ago, when the receipts exceeded 32*d.* per ton. Still it was far greater than in Dublin, where the only dues on goods were those on timber and stone, and the total revenue per ton was only 7·32*d.* It had been argued that Dublin being to so great a degree a free port as regarded goods, was an encouragement to trade; but it was questionable whether this argument had not been pushed too

Mr. Stoney.

Mr. Stoney. far, as a very small revenue seriously limited the funds available for new works and tended to cripple desirable improvements. With reference to the proposed experimental dredging on the Mersey bar, he did not anticipate that it would have any material effect. There could be no doubt, however, that a great improvement could be brought about by adopting the principle of concentrating the scour, which in Dublin had more than doubled the former depth on the bar, having increased it from 6½ feet to 16 feet at low-water.

Mr. Tapscott. Mr. R. LETHBRIDGE TAPSCOTT remarked that it was interesting to note how the older and smaller docks had been rendered more useful by an artificial means of increasing the depth of water, and by connecting them with the larger docks at the south end. This would prepare the way, in case of the future expansion of trade, for removing the intermediate quays and forming larger water spaces similar to those at the north end, and would thus enable the large ocean-going steamers of the regular lines to receive their passengers in dock, near the centre of the town, and avoid their exposure on the river by tender. The Author described the special features of the entrance to the new north docks, stating that it was decided to lower the level of the sill by 12 feet, and to maintain the necessary depth by means of sluices. Now this depth of 12 feet seemed considerable, and it would be worth while knowing if it was rendered necessary, by any change of natural level during the one hundred and eighty years for which actual data existed. This was the more important as the depth over the bar at low-water was now greater than it was known to have been at certain times. For, as the river walls straightened the course of the flow, and removed the little bays and sloping shores, the scouring effect of the ebb-waters must have materially increased, and should have had some effect in reducing the sandbanks. If the bar was considered as a reservoir dam, which simply kept the water in the river, then its maintenance was necessary to preserve the anchorage ground. If, however, there was a deep-water channel through the bar continuous with the anchorage ground, then any withdrawal of pressure, or severe wind storms and even under-currents, would tend to encourage an outward flow, and thus reduce the depth in the river at low-water, and endanger the usefulness of the anchorage ground, which would be a far more serious matter than the delay of ships waiting for water to cross the bar.

Mr. Thomas. Mr. JOSEPH THOMAS did not think the cranes in use at the Liverpool Docks would be suitable for discharging ships in the Royal Albert Docks, London; nor that the small quay space would be

Mr. Thomas. of much service in unloading the general cargoes and carrying on the work there. Tidal basins, in his opinion, without locks were only receptacles for mud, and not at all necessary; neither were basins with locks of any practical service, as the tidal basin of the Royal Albert Docks had not been used in that capacity for years, and only as an ordinary dock, the gates between the basin and the dock never being closed; and where a trade of such magnitude as at the Royal Albert Docks could be worked without difficulty, as many as twelve ships having been docked and undocked on a single tide, representing 32,700 tons, besides barges, a tidal basin was not wanted.

Mr. Thwaite. Mr. B. H. Thwaite believed it would be a useful measure of the efficiency of a dock system to compare the area of the docks, in acres, with the annual shipping tonnage; the rates arrived at would show the relative area of utility of the systems. It would be interesting if a comparison measured on this basis was instituted between the various British ports of the first magnitude. There was an impression, well founded or not, that many of the Liverpool Docks were practically useless owing to the enormous accumulation of silt in them and at their sills or entrances. With the exception of the general and admirable solidity of construction that characterized the docks of Liverpool, there was nothing that needed special comment. The main point of interest to the engineer was the sluicing arrangement devised by the Author. This arrangement, however, had a defect, which a little consideration would show it to be a serious one. Immediately at the commencement of the maximum velocity of the bottom, or ground currents of the flowing tide, just after high-tide, and the period of all others when the silt should be disturbed by the flow from the sluicing and raised into the swiftly-flowing currents, the head of water, in the catchment basin supplying the sluices, was so trivial as to be practically useless; and so the silt was removed a few feet farther into the river, not always even clearing the under surface of the pontoons carrying the St. George's landing stage. He thought the sluice principle was right, but that its application in this instance, was rather unfortunate. What was required to relieve the Mersey of the stigma of neglect, was the removal, not only of the accumulations of silt known as the Pluckington Bank, and the others that blocked up the entrances of the older docks, but of a part of the Mersey bar. Had such an obstacle interfered with a water-way of the same importance in the United States of America, it would long ago have been removed. He had suggested some years ago—in the Liverpool press—the utilization of an extension of the sluice

Mr. Thwaite. or hydraulic scouring principle to effect these objects. The idea had been successfully applied by the late General Stone in New York Harbour. It consisted essentially of the application of powerful turbines, placed on punts or barges, forcing water, at relatively high pressures, in numerous jets, obliquely and directly upon and under the surface of the silt, during the period only of the maximum velocity of the current at the bottom. The silt was thus raised into a state of suspension in the rapidly flowing currents, and was carried and deposited out at sea. By a persevering application of this nature he believed the Mersey bar and the silt accumulations would be reduced so as not to impede the progress of maritime navigation.

Mr. Wells. Mr. L. B. Wells observed that the enormous trade, originating in the densely populated manufacturing district at the back of Liverpool, rendered anything affecting that port of much interest to the nation, the ocean-going traffic from the great harbour on the Mersey at times exceeding even that of London; whilst any improvement which would enable the port to be used during longer periods of the tide, for access and egress by ships of the Royal Navy, might in stress of war be of equal if not of greater importance. While every one was struck with admiration at the grand docks that had been constructed, and were maintained with so much skill, travellers and merchants were generally heard to complain of the delays to be encountered in using them, due in great measure to the condition of the bar, which was impassable by deep-draught vessels for several hours each tide; in fact, such vessels, when possible, avoided crossing on a falling tide, while on low neap-tides, when there was only a depth of 30 feet or a little more, at the top of high-water, it must be extremely hazardous for vessels drawing 25 feet to 26 feet, as some of the liners did, and still more for those ships of the Royal Navy, drawing 27 feet to 28 feet to cross at all even when there was no sea on. At all times deep vessels were compelled to leave the docks the tide before they went to sea, and to anchor in the river, a somewhat dangerous and inconvenient proceeding, and there embark passengers, and complete loading, in order to pass the bar at the top of the next tide; while steamers that had perfected their appliances, and, at great cost, raced across the Atlantic in a few days, lost as many hours in waiting for water; meanwhile collisions and disasters occurred which would have been avoided if they could have proceeded at once to their destination. These difficulties were on the increase, owing to the disuse of subsidiary channels of approach; this had been brought about in part by the deterioration of those channels, as well as by the fact that ships had increased in size and draught of late years. The lighting and buoying of the sea-channels was well attended to, and necessarily so, for during the short winter days the Mersey bar could only be crossed by deep ships in the hours of darkness. The average daily traffic in 1888 in and out was one hundred and nineteen vessels; of these one hundred and two used the Queen's Channel, giving a total of thirty-seven thousand per annum; some six thousand passed by the Rock Channel, chiefly coasters, and only three hundred by the Formby Channel; the total number reaching forty-four thousand in and out, and this had been exceeded in former years. The necessity of improving the approach to Liverpool had often been before the Dock Board, and the late Mr. Laird, M.P., urged his colleagues to take action so long ago as 1874, when he stated that the depth of water on the bar was 7 feet to 8 feet, whereas it had been 12 feet previously. The normal depth that might be allowed for appeared to be about 9 feet, and meanwhile deep-water docks and entrances were being multiplied in all the chief ports, and in Liverpool upwards of 110 acres of additional water space had been provided in docks with sills deeper by 3 feet than any that were built on the Liverpool side prior to 1881; these were the busiest portion of the dock estate, and showed a far greater necessity for dealing with the bar than existed formerly. The whole trade of Liverpool suffered, for even coasting steamers trading to Ireland and Scotland were obliged to fix their "time bills" to suit the tides, and no regularity of train or steamer service was possible in connection with sea-going traffic. Such beneficial results had been obtained elsewhere from the regulation of tidal rivers, including the bars at their entrances, and in this country on the East Coast more particularly, that it could no longer be conceded to be a wise policy to leave the Mersey bar to Nature or chance. The undertaking was no doubt a great one; but the interests to be served were proportionately great, and demanded that an equivalent effort should be made. Great caution must be exercised, and rash attempts avoided; but, that the prodigious force embodied in a tide with a range of 30 feet flowing at 4 knots an hour, and in volume 500,000,000 cubic yards, could be compelled to do useful work, in a channel duly regulated with that object in view, must be admitted. Inside the bar, where a channel was confined by high sand-banks or narrowed by the Lancashire and Cheshire shores, the depth was 50 feet at low-water. The effect produced by the dock walls on either side pointed to the same conclusion. Formerly, exclusive of the Eastham Channel, there Mr. Wells.

Mr. Wells. were two channels leading to the Upper Mersey between Hale Head and Dingle, shown in the chart of 1835. These had become merged into one channel for many years, and an improved navigation to Runcorn was the result, so that vessels of far greater burden could navigate it. The direction of the main seaward channel had been much more stable since the Queen's Channel opened out, resulting no doubt from the training of the currents opposite Liverpool by the construction of the dock walls. Old surveys of Liverpool Bay were in existence, and surveys were now made at short intervals, and it did not appear that the total quantity of sand differed widely over long periods. The sand was silicious, not calcareous; the accumulation was in the main due to the subsidence of the land in perhaps not very remote periods. There was evidence of such a sinking in the Wirral district of Cheshire having taken place since the Roman occupation, and tree-trunks were found under the foreshore on the Lancashire side. The amount of fresh water entering the estuary was comparatively small, and so would be the detritus; and the latter would be greatly diminished when the Manchester Ship-Canal was made, in which much of it would settle. It was therefore the existing sands and the recurring tides that had to be dealt with. The Author pointed the way when he congratulated himself on the Rock Channel having a rock bottom which would not become deeper. Why should not this channel be closed and the Formby Channel also, thus concentrating the scour on the main channel. The proposal to dredge the bar was believed to be futile; harrowing was tried on the bar many years ago, by Admiral Denham, and more recently in the channel near Runcorn by Mr. Leader Williams, but abandoned as useless; sand that had been deposited by the elements, while the controlling conditions remained unchanged, would assuredly be deposited again. Prior to 1842 the conservancy of the Mersey, as well as the docks, was in the hands of the Corporation of Liverpool. At that time an enquiry was held with the result that the conservancy of the Mersey was vested in three Cabinet Ministers, namely, the First Lord of the Admiralty, the President of the Board of Trade, and the Chancellor of the Duchy of Lancaster. They appointed an Acting Conservator, whose salary was provided by the Mersey Docks and Harbour Board, and this officer watched the estuary, and made an annual report, which was printed under the authority of Parliament. The present Acting Conservator, Admiral Sir George Richards, was well known as a surveying officer, and a former hydrographer to the Admiralty. The ministers had no funds at their disposal, and were powerless to take action; they were, however, in a position to prevent injurious action being taken by others. They could very properly set on foot another public enquiry after the expiration of nearly fifty years since the last one was held, and at a time when the due completion of the Manchester Ship-Canal was within measurable distance, and provide that the entire question of the Conservancy of the Mersey, which was now involved in their own powers, those of the Mersey Docks and Harbour Board and the Upper Mersey Commissioners, should be reviewed and re-adjusted on a basis more suitable for the requirements of the estuary, and of the interests involved. A clearly defined authority should be made responsible for the condition of the sea-channels. The late Chairman of the Mersey Docks and Harbour Board disclaimed any responsibity resting on his board. If that was so, H. M. Government must be held responsible, and the people of Lancashire and the north-western counties should seek that conjointly with the improvement of navigation inland, steps should be taken to carry this to seaward also. When in addition to the £17,000,000 sterling spent on the Mersey Dock Estate, an additional £8,000,000 had been laid out for navigation purposes on the Manchester Ship-Canal, and a largely increased industrial population was located on the banks of the canal, the necessity for dealing with the bar would become, if possible, more urgent than heretofore. He looked upon the question of the improvement of the Upper Mersey as shelved by the construction of the Manchester Ship-Canal. He had known this estuary from 1865, when Resident Engineer at Runcorn Bridge, and being subsequently employed at Ellesmere Port, Garston and Weston Point. The Ship-Canal would accommodate all the Cheshire side and through traffic, while the Widnes trader had obtained clauses from the Ship-Canal Company. They had a traffic of some million tons per annum; but this of itself would not warrant the outlay necessary for the improvement of the upper estuary. Mr. Wells.

Mr. Wheeler. Mr. W. H. Wheeler observed that, amongst the various works carried out by the Author, he was most struck with the successful results attending the sluicing arrangements for clearing away from the entrances to the docks the sediment brought in by the tides. The upcast pipes, with disks for spreading the water, at the entrance to the Langton Docks, at the part beyond the reach of the wall sluices, were especially ingenious. The satisfactory results of these sluicing arrangements confirmed the idea, that he had long held, that the transporting power of water might be more

Mr. Wheeler. frequently applied to the removal of deposit than was the case, and he ventured to throw out a suggestion whether this principle could not be still further applied to the removal of the shoals along the river wall, which obstructed the entrance to the docks at the north end; and whether the sluicing operations for the removal of the Pluckington Bank could not be aided by mechanical erosion. He had recently been carrying out some practical experiments to test this theory for the removal of shoals. After a number of trials, with models of different forms, he had succeeded in obtaining an eroder which, while absorbing a small amount of power to work it, thoroughly disintegrated the material operated on, churned it up, and mixed it so completely with the water, that, while the effluent stream became only in the same turbid condition as when a land-fresh was coming down, it yet removed an immense amount of material. The machine, as temporarily arranged for experimental purposes, consisted of an ordinary barge, capable of carrying about 30 tons. At the stern of this was fitted a wooden frame, capable of being raised or lowered by a winch on board. This frame carried a vertical shaft having at the lower end the eroder, and at the upper a bevel-wheel driven with belting by a 6-HP. portable engine. The eroder revolved at the rate of 120 revolutions a minute. The barge being moored a-head was warped backwards and forwards by side-ropes worked by a winch, over a space from 50 to 60 feet in width, and also gradually worked a-head against the stream. The machine thus arranged was set to work on a shoal which had been gradually accumulating along the jetty at the entrance to the dock under his charge at Boston. The shoal in places had risen to 8 feet above the sill of the dock, and extended out 50 feet into the channel. It consisted of clayey silt, so compact that the water from the sluices used for clearing the entrance had no effect on it. Owing to its position, the short time at which a dredger could work at it, and other circumstances, the removal of a portion of this shoal had previously cost at the rate of 1*s*. 6*d*. per barge-ton. Working three tides, or twenty-one hours in all, the eroding dredger removed 1,500 tons, at a working cost of £4 6*s*. 6*d*., equal to 0·75*d*. per barge-ton, or 1·10*d*. per cubic yard *in sitû*. The saving effected in the removal of this quantity on the old method more than repaid the whole cost of fitting up the machine, which was about £75. It had since been employed in removing the rest of the shoal, and also in lowering the approach-channel, the bottom of which was hard boulder-clay mixed with chalk and stones. The eroder disintegrated the clay, and mixed it with the water in the form of the finest mud. The

Mr. Wheeler.

entrance being off the main channel, the velocity of the current was only from ½ to ¾ mile an hour, increasing to 1½ mile an hour in the main stream. Very careful soundings since taken showed that the whole of this sediment had been carried away by the ebb-current, and deposited in the estuary, none being left in the river. The quantity of matter in suspension in 1 cubic foot of water, at 10 feet from the eroder, was 2,424 grains, this proportion rapidly diminishing as the distance increased, and the particles became more distributed, the quantity of solid matter in suspension at 100 yards being only 67 grains per cubic foot. He would suggest, as worthy of consideration, whether this system could not also be applied to the removal of the bar of the Mersey, and the transporting power of the ebb-tide utilized for removing the sand of which it was composed. A machine designed on this plan would, he thought, be more effective in its results than the propeller sluicing adopted on the Columbia river;[1] its frame and eroder, being capable of being raised or lowered, could work effectively for a longer time than the propeller of a steamer. The frame of the eroder also being balanced, and its effect reaching some distance beyond its actual contact with the material, it would not be affected by a slight lift of the sea in calm weather at the bar of the Mersey. The machine was of a very simple character; the cost of a boat constructed for the purpose, with eroding machinery complete, he estimated would not exceed £1,500; and basing the cost of working on what had been found practicable by experience, say 1*d.* per cubic yard for the material *in sitû*, the removal of 500,000 cubic yards, as was now suggested, from the bar of the Mersey, would amount to £2,083, or a total cost of £3,583, as against £10,000, the estimated cost of raising the sand by the machinery which the Mersey Docks and Harbour Board proposed to experiment with. With regard to the Author's contention, that the maintenance of the Mersey as a great tidal receptacle mainly depended on the roving character of the channels, and their incessant wanderings through the wide expanse of sand in the upper estuary, his experience of rivers passing through sandy estuaries was in direct variance to it. He had found, as the result of works with which he had been connected, and others which had come under his direct observation, that by fixing channels passing through sandy estuaries in one place, and so preventing this roving tendency, their depths and capabilities for navigation had been greatly improved. All the rivers which discharged through the sand at the

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxiii. p. 386.

Mr. Wheeler. head of the Wash on the East Coast had been benefited by being trained and fixed in one course. Formerly, the tides and fresh-water currents were perpetually stirring up this sand and loading the water with detritus. The tide thus came up the river charged with sediment, which in the absence of freshets in summer was left on the bed of the river, raising it several feet. In winter the energy of the freshets was absorbed in removing this deposit, and in stirring up the sand. Since the training, the tidal water came up clear, and there was no deposit in the river. The freshets carried the alluvial matter with which they were charged away to sea, and exercised their energy in clearing and deepening the navigable channel, instead of transporting the sands from one side of the estuary to the other. It appeared to him that, making both the tidal and fresh water in the upper estuary of the Mersey pass up and down one deep defined channel, free of deposit, would have more effect in keeping open the sea-channels than if loaded with the detritus derived from the constant frets and stirring up of the sands. The training of the channel would not create any fresh material. The sands would no doubt become fixed, and the bed of the estuary raised, and even perhaps grassed over for a certain limited area; but it would not necessarily follow that there would be less cubic capacity for the tidal water; the loss in the higher part would be compensated by the increase over the area lowered by the transport of the sand to the part raised. Any decrease of tidal capacity could only arise naturally from sand brought up by the tides from the sea, or by alluvial matter brought down by the rivers, and in either case deposited and permanently left in the estuary. A deep defined stream would be more capable of carrying back sand thus brought up by the tides, or of transporting to the sea alluvial matters brought down by the rivers, than a shallow stream wandering about the estuary loaded with the silt disturbed in its course, and thus it would be more effective in preventing permanent deposit, and preserving the capacity of the estuary as a tidal receptacle. While fully agreeing with the Author that tidal water brought into an estuary was of great value in maintaining sea-channels, and that any works likely to curtail the amount of such water ought to be watched with jealous care, yet the principle might be carried too far. A better result could frequently be attained by judicious training, and causing the tidal water to concentrate its energy and exert its power with the greatest effect, than by preventing improvements by a policy of non-interference with the natural condition of an estuary.

Mr. Lyster. Mr. G. F. LYSTER, in reply to the correspondence, referring to

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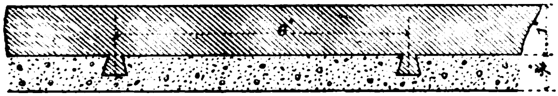
Mr. Carr's inquiries, said that the harbour-master's ordinary staff of dock gatemen were all on duty at high-water of every tide, but at other times few of them were on duty, so that the running of the sluices where these were numerous was generally looked after by a special staff of "water-runners." Of course, in the Langton Dock, as in all the Liverpool Docks, more especially those opening direct from the river, there was a large deposit of mud, which had to be removed from time to time by dredging. The dock gates on the Mersey were now built entirely of greenheart, which had proved in every way a most excellent material for the purpose. The coating on the inside of the cast-iron sluicing culverts was of Portland cement mixed with fine gravel, the layer being ¾ inch in thickness. It was secured by annular dove-tailed ribs 6 inches apart, *Fig. 4*. Examination, from time to time, showed that the condition of the pipes continued perfect. No trouble had been experienced from silt within the sluicing-pipes. The rush of water in the pipes prevented any deposition of silt within them, and the frequent use of the sluices cleared them of any ordinary deposit, no other means of clearing any of the pipes had been necessitated. He could not quite follow Mr. Thwaite in certain of his remarks. As regarded the idea which Mr. Thwaite seemed to entertain, that many of the Liverpool Docks were practically useless, owing to the enormous accumulation of silt in them and at their entrances, he did not know to what this could refer unless to the Pluckington Bank, which, as stated in the Paper, extended in front of the Southern Docks, and which he had taken in flank by providing deep-water entrances at the extreme south end, from which the older docks could be approached. Certain of those docks were now impounded over neap-tides, and their depth was maintained where necessary by pumping from the river. This impounding scheme had brought into full use as deep-water docks a group 50 acres in area, and having 2 miles of quayage, which, but for such an arrangement, would have comparatively gone out of use for deep ships. A similar system of impounding had been adopted at Birkenhead, affecting about 150 acres of water-space, and 8 miles of quayage, and this would shortly come into full use.

Fig. 4.



Mr. Lyster. He hoped to contribute a Paper on the subject of these impounding and pumping systems at some future date. Again, as regarded sluicing, neither at the Canada Basin nor at the landing stage had a bank been formed by the action of the sluices, as might be inferred from Mr. Thwaite's remarks. He failed to see the meaning of the word "unfortunate" in this connection. The circumstances attending the successful working of the landing-stage sluices had been fully set forth in a Paper[1] communicated to the Institution by Mr. W. H. Le Mesurier in 1887, to which there was nothing to add except that, amid the many variations of the Pluckington Bank, the stage continued to be maintained in safe working condition. Mr. McConnochie had referred to the inconvenience of having the shed so near the dock as was generally the case at Liverpool. To this he would reply that for most cargoes the balance of convenience seemed to lie with this arrangement, although in some exceptional instances, such as where large cases or pieces of machinery had to be put aboard a ship, it might be desirable to have a wider margin. There could be no doubt, however, that the desire of the parties working the cargo was to get it under cover as soon as possible. As regarded the speed of working of the roof-cranes, he did not think the extra length of crane-chain practically diminished the rate of speed of working. As a matter of fact, the crane could work much faster than the cargo could be unstowed and slung. He had rather understated the average rate of work of the cranes. The returns for two years showed that the average number of lifts per working hour during that time was thirty-three; of course in many of these hours the rate was much higher. It was to be borne in mind that the weight lifted each time was generally much higher than in the case of steam-winches, or such appliances. It was usual for these 30-cwt. cranes to lift more than a ton each lift. The cranes were designed to make ninety lifts an hour, and could do so if the stuff were slung and unslung with sufficient rapidity. Their position did not, in his opinion, in any way involve slow working. With regard to the remark that the small quay-space would not be of much service in unloading the general cargoes and carrying on the general work of the Albert Docks, London, one of the double-story sheds at Liverpool gave a covered floor area having a total width of over 180 feet, which could not be considered a narrow quay-space; and in fact there were few, if any, ports in which so much quay-space could be obtained. For the service of the double-story sheds, say 3,000 feet in length, twenty cranes of

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[1] Minutes of Proceedings Inst. C.E., vol. xc. p. 308.

Mr. Lyster.

30-cwt. power were provided. As to the seniority question of Liverpool *versus* London, it appeared from the evidence adduced by Mr. McConnochie, that at the date of the writing of the notice quoted, which date was not given, the Howland Great-Wet Dock had two pairs of gates, and although it was not distinctly stated that in 1703 (at least nine years before the notice was written) or in 1715, both of which dates were mentioned, the dock had gates, he supposed, in the absence of evidence to the contrary, the dock was at these times in the same condition as at the date of the notice. If it were so, the claim of the Liverpool Old Dock, for which the Act was obtained in 1709, and which was opened in 1715, to be regarded as the first wet-dock, could not be sustained. With respect to the Liverpool Datum, as to which an inquiry had been made, the depth of water on the Old Dock Sill was the readiest and most useful measure of the tide, so far as it affected the shipping; and as other docks were constructed their sills were also referred to the Old Dock Sill, which was thus established as the local datum. There would not be any advantage in adopting a different datum. The Ordnance Datum was a level decided on from tidal observations made at Liverpool in 1844, and was the mean level of the sea at Liverpool during those observations. He might say, in passing, that it appeared from subsequent and more extended observations, that the mean level of the sea was considerably higher than the Ordnance Datum. He could scarcely add anything further in respect to the bar. The depth of water on the bar was never quite constant, though for many years there had always been a depth of about 10 feet, more or less. The latest chart issued by the Marine Surveyor of the Board, that of 1890, showed a depth of 12 to 13 feet on the bar. This was from a survey made in August 1889. With all due respect for Mr. Cunningham's experience in the Tay estuary, he could not agree that the work of deepening the bar of the Mersey would be by no means a very difficult, costly, or hazardous operation. He fully appreciated the value of "eroders" or "disturbers" for assisting in removing accumulations of silt; but their application at New York had not been the success which Mr. Thwaite seemed to think. The "hydraulic plough," the form of disturber tried at New York, had failed to do the work for which a contract was taken by those interested in it; and the improvement in the channel of New York Harbour had been brought about by the use of sand-pumps alone. Again, he could not concur with Mr. Thwaite in referring to the Mersey bar, that "had such an obstacle interfered with a waterway of the same importance in the United States of America, it

Mr. Lyster. would long ago have been removed." The New York sea-channels, of not less importance than those at Liverpool, and the condition of which presented most grave obstacles to vessels of deep draught, had only within the last few years been seriously attacked, although in Mr. Lyster's opinion presenting a much less difficult problem to deal with than Liverpool, and although the port of New York brought a revenue in Customs dues and otherwise, compared with which that of the Mersey Dock Estate was but a trifle. There could be no doubt that the question of amelioration of the bar was a large one, and not to be dealt with rashly.

21 and 28 January, 1890.

SIR JOHN COODE, K.C.M.G., President,
in the Chair.

The discussion on the Paper by Mr. G. F. Lyster, on "Recent Dock Extensions at Liverpool," etc., occupied both evenings.

4 February, 1890.

Sir JOHN COODE, K.C.M.G., President,
in the Chair.

The following Associate Members have been transferred to the class of

Members.

Walter Young Armstrong.
John Harry Hallett.
Edward Brough Taylor.
John Francis Weedon.

The following Candidates have been admitted as—

Students.

George Hannyngton Baker, B.A.
Francis Edward Bull.
Archibald Currie, Jun.
Ernest Cranston Given.
William Brice Gregson.
William John Howley.
William Ingham.
Kerr Lockhead, B.Sc.
D'Arcy Marriott.
John Claridge Nicholl.
Henry James Orford.
Alban George Robins.
Bhagat Ram Sawhny.
Francis Albert Basil Schütte.
Archibald Edward Walker.
Wilfred Le Plastrier Webb.

The following Candidates were balloted for and duly elected as

Honorary Member.

General Edward Frome, R.E.

Members.

Andrew Brown.
Frederick Benbow Hebbert.
John Lanyon.
Gustav Lindenthal.
Augustus Worthington Topp.

Associate Members.

Alfred Edward Ainsworth.
Harry Ashwell.
Maunsel Caswell Bannister.
Frederick William Besant.
Thomas Johnstone Bourne, Stud. Inst. C.E.
Keshavji Shamji Budhbhatti.
George Harley Bulmer.
Samuel Watkin Carlton, Stud. Inst. C.E.
William Innes Christie.
John William Cockrill.
Charles Henry Colson, Stud. Inst. C.E.
Francis Dundas Couchman, Stud. Inst. C.E.

Associate Members—continued.

John Cowan, Jun., Stud. Inst. C.E.
James Hening Cuming, F.C.H., Stud. Inst. C.E.
Robert Charles Dyson, F.C.H.
John Edward Fitt, Stud. Inst. C.E.
John Reed Fothergill.
Guilherme Henrique Fox.
Thomas Bernard Hall.
Hector William Baillie Henderson, Stud. Inst. C.E.
David John Highet.
Herbert Ross Hooper, M.A., Stud. Inst. C.E.
William George Crawford Hughes, Stud. Inst. C.E.
Sidney Herbert Hunter.
David Morgan Jenkins.
Archibald Thomas Mackenzie.
William Charles McClew.
James Morgan.
Peter Augustus Ransom, B.A.
Harry Richardson.
William Lloyd Roach, Stud. Inst. C.E.
John Robins.
Charles Hugh Romanes, Stud. Inst. C.E.
Percival Ross.
William Henry Stanley.
Robert William Lyons Tooze.
Thomas Frederick Veasey.
John Robert Mosse Wright.

(*Paper No. 2438.*)

"Bars at the Mouths of Tidal Estuaries."

By William Henry Wheeler, M. Inst. C.E.

Bars at the mouths of tidal rivers and estuaries, although frequently referred to at the Institution, have not formed the subject of a separate Paper.

The variety of opinions expressed as to the cause of the existence of bars, and the most effectual way of dealing with them, together with the importance of the subject as affecting the efficiency of the navigation of tidal rivers, appear to warrant the reading of a Paper which may lead to a discussion, and be the means of eliciting information of sufficient value to record in the Minutes of Proceedings.

In dealing with navigable rivers, it is essential that a careful consideration of the causes that have led to the existing conditions of the channels should precede any attempt to carry out works for their improvement.

With this object in view, it is proposed:—

(1) To describe the different kinds of bars;

(2) To treat of the causes of their formation; and

(3) To mention the remedies that have been, or may be, applied for their removal.

In this Paper, the term River will be applied to that portion of the channel which lies within banks sufficiently high to prevent the water at high-tides from any lateral flow; and the term

Estuary to the part below the fixed channel, which is covered by salt water at every spring-tide. A Bar may be defined as a ridge either of fixed or of movable material, running across an outfall-channel near its junction with the basin into which it is discharged, having the water on both its upper and lower sides deeper than on the crest. The extent to which this ridge rises above the general bed of the outfall-channel is the measure of its obstruction to the navigation.

Bars may be divided into four classes:—

1. Those consisting of hard material not affected by the scour of the current.

2. Those due to the deposit of alluvial matter brought down by rivers draining large areas of country, and discharging into tideless seas, or where the rise of tide is very small.

3. Casual bars of shingle or sand, occasionally heaped up by the action of waves in heavy gales, and afterwards dispersed by the currents.

4. Bars consisting of sand or shingle, which, while permanently retaining their general features, are constantly subject to alteration from effects caused by winds, waves, and varying currents.

Bars composed of hard material consist generally of rock, very hard clay, or large boulders, rising above the general level of the rest of the bottom of the outfall-channel. In this case the removal of the material of which the bar consists can only be effected by dredging. When this is accomplished the bar does not form again, and the improvement is permanent.

The bar across the mouth of Lough Carlingford, on the east coast of Ireland, may be quoted as an example of this class. It consisted of hard clay mixed with stones, some of which weighed as much as 4 tons. Through this bar a channel 400 feet wide, with a depth of from 14 to 18 feet at low-water, was dredged. Considerable difficulty was experienced in carrying out the work from the limited number of days on which the dredger could be used, owing to the roughness of the sea.[1]

The Tay is encumbered with an inner bar, about 6 miles above the outer bar, consisting of boulders and hard gravel, so heavy and compact as to be uninfluenced by the currents. The crest of this bar is 4 feet above that of the outer one.

Bars due to the deposit of alluvial matter are caused by the action of river-currents, bringing down large quantities of earthy matter in suspension. This alluvium settles at the mouth of the estuary,

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[1] Minutes of Proceedings Inst. C.E., vol. xliv. p. 131.

forming deltas, through which the fresh water finds its way to the sea by several shallow channels. In some deltas the varying action of the ordinary and flood-discharges causes the formation of bars, which limit the water available for navigation to the depth over their crests.

The Danube may be quoted as an example of a river discharging into a tideless sea, on which a distinct bar is formed by the action of the outgoing current alone. Sir Charles A. Hartley, K.C.M.G., ascribed the formation of the bar in this case to the surcharged current of the river, after leaving the embouchure, meeting with resistance from the comparatively stationary water of the sea, thus losing its velocity and depositing the material held in suspension, the deposit forming the bar.[1]

Where a fresh-water stream discharges into a basin containing salt-water, the water does not readily mingle, but the fresh water extends out for some distance on the surface of the salt-water. It is stated that the effluent water from the Rhone extends from 9 to 11 miles from the junction of the river with the sea in a thin film on the top. The fresh water, on rising to the surface, abandons the material it has in suspension, and thus accumulation takes place round the mouth.

The Mississippi is an example of a river discharging into a sea where, although the rise of tide is exceedingly small, it is the cause of the formation of the bar. This is described by Messrs. Humphreys and Abbot as due to the fact that, during the period of floods, the water in contact with the bar as far as its crest is fresh, and moves seaward with a comparatively rapid current. Beyond the outer crest, and below the stratum of fresh water, salt-water comes in contact with the outer slope of the bar moving seaward. The fresh water as it enters the gulf rises upon the salt-water, at an angle inversely as the strength of the current. The current is able to roll the detritus along the bottom until the river water begins to ascend upon the salt-water of the gulf, when the rolled material is left upon the bottom in the dead angle of the salt-water. A deposit is thus formed which produces the bar. On the occurrence of subsequent floods, when the velocity of the fresh-water current is increased, erosion takes place on the previous season's deposit, at the angle where the current is deflected upwards; the new matter rolled along the bottom is pushed over the bar and dropped in advance, and the bar progresses further seaward.

Deltas and Sandy Estuaries.—A distinction must be drawn

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[1] Minutes of Proceedings Inst. C.E., vol. xxi. p. 282.

between deltas formed as last described and estuaries encumbered with sands.

The former consist of a continually-increasing deposit due to alluvial matter brought down by river currents, and are found at the mouths of rivers where there is little or no tide, and where consequently the scouring action is due almost entirely to the fresh-water current.

The delta of the Danube is the result of the detritus brought down from a drainage area of 300,000 square miles, which amounts annually to over 68,000,000 tons. The Mississippi and the Nile afford examples of rivers of great magnitude discharging through deltas into seas where the rise of tide is so small as to be entirely overpowered during the time that land floods prevail. The fresh-water discharge of the former amounts to 675,000 cubic feet per second, the rise of tide being only from 1½ foot to 3 feet. The quantity of material brought down is estimated at 362,750,000 tons in a year. The Ganges has a very large delta, although the rise of the tide is as much as 17 feet; but the quantity of water discharged in floods is so enormous, as to override the tidal currents, and at such times the downward flow never ceases.

In tidal estuaries covered with sands, the amount of material with which the outfalls are encumbered is not the product of matter brought down by the rivers, but is the result of some mighty operation of Nature in past ages. Probably, at the close of the Glacial period, the melting of enormous masses of ice caused the torrents, which gave the rivers of this country their main direction and features, to deposit the immense masses of sand which now encumber some parts of the coast. The result of the conflict which then took place between the fresh-water torrents and the tidal currents resulted in a balance of forces, and the determination of the relative position of the sands and channels, which have been maintained up to the present time.

Owing to a long course of winds from one direction, the sandbeds may shift and the channels vary their position; but this is only a transport of material, and unlike the accretion which is constantly taking place in an alluvial delta, the normal quantity of sand remains the same.

Through these beds of sand the various channels maintain their width and depth mainly by the aid of the tidal currents.

The alluvial matter brought down by the rivers is either carried away to sea or deposited on the shores, where it slowly accretes, and in time forms the salt marshes generally to be found in all estuaries.

Any alteration in existing conditions disturbs this balance of forces. If the quantity of tidal water be diminished, the channels will deteriorate; if increased, they will be improved.

Casual bars are frequently met with on sandy coasts. The coast on the south side of the Straits of Dover is encumbered with large masses of sand, which, reaching from the north-east past Ostend and Dunkirk, extend southward past Calais and Boulogne. A strong gale from the north-east causes the sea to be so rough that the sand stirred up by the waves is drifted and deposited in the comparatively slack water at the mouth of the harbours, causing a bar which rises several feet above the general level of the bottom of the channel. This deposit remains until gradually dispersed by the action of the waves during westerly gales. After a gale lasting three days the quantity of sand deposited at the end of the pier at Dunkirk was estimated by Mr. Plocq, the Engineer, at 40,000 cubic yards.

Bars at the mouths of sandy estuaries, while the most frequently met with, are those concerning which there is the greatest diversity of opinion. The features of these bars are of a most remarkable character. They consist of one or more ridges or mounds of material, the particles of which have not the slightest coherence, yet stand with a slope much steeper than the natural angle of repose of the material. Rising in some cases as much as from 40 to 50 feet above the bottom, they maintain their positions across channels subject to a tidal rise of from 20 to 30 feet, through which currents are running at a rate frequently exceeding from 3 to 4 knots an hour, and the direction of which is reversed three times every day. Exposed to all the storms and waves of the open sea, they are sometimes partly dispersed or added to, altering in width and height and changing their positions, yet having a normal condition, to which they are restored when the disturbing causes cease.

The most notable example of a bar of this class is that of the Mersey (Plate 5, Figs. 9 and 10), which, extending across the channel from a mass of sandbanks on either side, has on its crest at low-water a depth of 9 feet, while in the channel on the inside there is a depth of about 50 feet, and on the sea side 42 feet. During the last fifty years the low-water channel of the Mersey has altered its position three times, yet every new channel has been accompanied by a bar of sand across it, notwithstanding that the low-water for about 12 miles on the inside runs through a deep rocky channel having a depth of from 30 to 50 feet, and that there is a range of tide of about 30 feet.

The bar at the mouth of Boston Deeps is almost as remarkable (Plate 5, Figs. 7 and 8). "The Wash," on the East Coast of England, is divided into two parts at low-water by a long narrow bank of sand, which extends for 15 miles between the two channels. The sides of this bank at the lower end are so steep as to be nearly vertical, there being a depth of 20 feet at low-water close up to the sand. Lynn Deeps, on the south side, is 7 miles wide at the mouth, and has a depth of from 80 to 90 feet at low-water of spring-tides. Boston Deeps, on the north side, is only ¼ mile wide at the outfall, and has a bar with only 12 feet on it at low-water. This bar extends over a length of about 1 mile, and consists of three ridges of sand, which are so narrow that the depth of water within a single cast of the lead varies a fathom. Spring-tides rise 23 feet, and set over the bar. The channel shoals from 5 fathoms on the inside to 2 fathoms on the bar, and then deepens to 4¼ fathoms outside. The ridges, although continually altering their form, maintain a general uniformity, and are subject to little alteration in gales or calm weather.

Bars are not common to all tidal rivers, nor when they do exist are they in all cases impediments to the navigation; they occasionally only mark the place where the water shoals from the sea to that of the estuary. In some estuaries where the depth at low-water at their entrance is very great, and more than sufficient for all purposes of navigation, ridges and depressions similar to bars in shallow rivers are to found, but, owing to the great depth of water over them, cannot be deemed bars.

The Thames, the Humber, the Forth, the Seine, the Scheldt, are all encumbered in their outfalls with large masses of sandbanks, but through these the tidal streams always maintain at least one deep navigable channel to the sea.

The bars that formerly existed on the Tyne, on the Tees, and on the Ribble, cannot be regarded as impediments affecting the navigable depth of water, inasmuch as the depth in the channel a short distance above the bar is as shoal or shoaler than that on the bar. On the Tyne (Plate 5, Fig. 13) the depth outside the bar in 1860 at low-water of spring-tides was 50 feet; on the bar it was 6 feet, at ½ mile inside the depth increased to 12 feet, and at 1 mile to 30 feet. It then shoaled to 4 feet 6 inches, deepening again to 32 feet 6 inches, and shoaling again to 6 feet just below the entrance to the Tyne Dock about 2½ miles above the bar, so that the depths on the bar and in the channel were nearly the same.

In the Tees (Fig. 15) in 1851 the depth immediately outside the bar was 21 feet at low-water of spring-tides; on the bar, 7 feet; immediately inside, 30 feet. At 1 mile the water shoaled to 9 feet; at 2 miles it shoaled to 6 feet, the available depth continuing to decrease above this. In the Ribble (Fig. 11) the depth immediately outside the bar at low-water of spring-tides is 30 feet; on the bar, 6 feet; immediately inside, 24 feet. The water then shoals at 2 miles to 6 feet 6 inches.

In these and other cases that might be quoted, although genuine bars exist at the mouths of their estuaries, they cannot be said to be in themselves impediments to the navigation.

THEORIES AS TO THE CAUSE OF BARS.

Various reasons have been advanced to account for the existence of bars. These generally may be divided into two classes, one ascribing the bar to inward and the other to outward influences. Of these the following is a summary:—

1. The deposition of the detritus carried in suspension by a river when it enters the sea, either from the slackening of the velocity of the current owing to increased area; or to the meeting of two currents which neutralise each other; or to the effect of the inflowing tidal water which, from its specific gravity being greater than that of the fresh water, checks the lower stratum of the ebb current and causes deposit.
2. To the form and direction in which the ebb and flood currents meet at the outfall, frequently involving a conflict resulting in eddies and deposition of material in suspension.
3. To the form of the estuary and an insufficiency of back water.
4. To the difference in duration of the ebb and flood currents, and the variation in the inclination of the slope of the low-water line in the estuary.
5. To the action of the waves driven along the shore, in piling up detritus in the direction of their greatest force.

As to bars being formed by detritus carried by the ebb.—With regard to the theory which ascribes the bar to the deposit of detritus carried in suspension by the ebb current, this may be applicable to estuaries into which a large quantity of fresh water is discharged, and where the rise of tide is small, but does not apply to rivers where there is any considerable range of tide, for the following reasons.

The material brought down by a river consists of alluvial matter, the particles of which are so small that they can be carried in suspension. If these reach the bar they are too light to remain there, and are carried to sea. The material of which bars are formed consists of coarse sand, the particles of which are too large to be carried in suspension.

This fact seems to dispose also of the theory that the bar being the nodal point where the action of the tidal currents is reversed, deposit takes place during the slack period. If there be no matter in suspension of the kind of which the bar is composed there cannot be any deposit. The nodal point also is not confined to any one place, but is continually shifting, owing to the varying height of the tides and the effect of winds.

The theory that attributes bars to the conflict occasioned by the meeting of the fresh and salt-water seems to be disposed of by the fact that, while the bar remains practically in the same position, the point where the fresh and salt-water meet varies with every tide. The salt-water pushes its way up along the bottom underneath the ebbing fresh water, and finally heads it back, the position where this occurs depending on whether the tides are springs or neaps, or the direction of gales. If this theory were correct there would be bars at the mouths of all tidal estuaries.

Effect of fresh water on bars.—Importance has been attached to the volume of fresh water coming down a river as affecting bars. In fact their very existence has been ascribed to a deficiency of fresh water. The late Mr. W. R. Browne in a Paper on "The relative value of tidal and upland waters in maintaining rivers, estuaries, and harbours,"[1] contended that the fresh water was the main and essential agent in keeping clear the channels of tidal rivers.

The Author's experience has led him to an entirely different conclusion. That fresh water alone, however great its volume, is not competent to keep the outfall channel clear and free from a bar, is shown by the case of the Mississippi, with its enormous drainage area of nearly a million and a quarter square miles, and a mean discharge of nearly three quarters of a million cubic feet per second; and by the fact that many of the rivers having the largest discharges of fresh water, and absence of tidal flow, are those that are most encumbered at their outfalls. Where the estuary is small as compared with the magnitude of the river, and the bar consequently near to its mouth, land floods may increase the depth over the bar at low-water, the additional quantity giving increased scour and exercising a beneficial effect.

Thus the bar at the mouth of the River Douro is considerably

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[1] Minutes of Proceedings Inst. C.E., vol. lxvi. p. 1.

improved by land floods, which are exceptionally heavy, the discharge being fifteen hundred times as great as the ordinary flow. The outfall of this river is protected by a wall which runs out on the north side. The detritus drifted along the coast accumulates at the end of this wall, and forms the bar, the depth of water on which varies from 14 to 17 feet. The rise of spring-tides is about 11 feet, whereas heavy land floods have been known to rise as much as 33 feet 9 inches, and to run down the channel with a velocity of 16 knots an hour. The discharge of the fresh water during these floods is twenty-eight times as great as the tidal water at spring-tides;[1] this, however, is a very exceptional case.

Generally in tidal rivers the size of the estuary is such that the land water bears a very small proportion to that of the tidal water. The fresh water coming into an estuary at its upper end during heavy freshets takes up space that would otherwise be occupied by tidal water. The tidal water being unlimited in quantity, fills the space available for it to occupy; if any portion of this space is filled with fresh water there is so much less room for tidal water. The level of high-water in the tidal estuaries of this country, with few exceptions, remains unaltered during the heaviest land floods. It is only during the last of the ebb that the water from such floods can add to the scouring effect on the bar. Where the estuary is large the quantity passing out over the bar will be the same whether freshets prevail or not.

The intermittent character of fresh-water floods also disposes of their value as the governing factor in maintaining the outfall.

In a large river like the Thames, which has a drainage area of nearly 6,000 square miles, it can hardly be contended that occasional heavy land floods account for the absence of a bar at the mouth of its estuary. Even as high up as London Bridge, 43 miles from the mouth, the tidal water is six times as great as the fresh water in floods. Mr. J. B. Redman estimates the quantity of tidal water flowing up between Teddington and Gravesend as nine times as much as that of the fresh water in heavy land floods. At the Nore the proportion will be very much greater. The Humber, which drains 10,500 square miles, discharges in floods a volume equal to about one-eighth of the tidal flow, the ordinary daily flow of fresh water being equal to one-eightieth of the tidal flow. This river also affords evidence against the theory that bars are due to alluvial matter in suspension brought down by rivers. Not only does it receive an enormous amount of detritus brought down

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[1] Minutes of Proceedings Inst. C.E., vol. lvii. p. 364.

by the Trent and the Ouse, but it also has carried into it, by the flood-tide in stormy weather, detritus arising from the washing away of the clay cliffs, which extend some miles to the north of Spurn Point, yet it has no bar at the outfall.

Neither can it with reason be said that the smallness of the watershed of the Mersey, which drains 1,706 square miles, is the cause of its bar. The volume of tidal water flowing up its channel amounts to 500,000,000 cubic yards each tide, as compared to only 2,000,000 cubic yards of water derived from land floods; the total quantity of tidal water which passes and repasses over the sand banks between New Brighton and Formby Point is 1,520,000,000 cubic yards. Nor can the bar of the Tay be ascribed to a deficiency of fresh water, this river having the greatest discharge for its drainage area of any river in Great Britain, and almost equal to that of the Thames; yet the quantity of tidal water, as given by Mr. Stevenson, is forty times as great as that of the freshets during high land floods.

In sandy estuaries heavy freshets may even tend to diminish the depth of water on a bar. The general effect of freshets is to alter the direction of the channels and impair their efficiency by making them wider and shallower in the process. In a long continued absence of a flood from the river the tidal current has the mastery. It scours out a channel to a certain depth, and then maintains it without much variation. So long as there is no change of direction there is little scouring or movement of sand. In the event of a heavy freshet the fresh water coming from a different direction to that of the tidal current strikes out a new course, cutting a fresh channel through the sand, and in so doing stirs up the material and throws it into the current. A portion of the material so disturbed and mixed with the water is carried gradually downward. On reaching the bar it is rolled over the steep edge on the seaward side to be carried back by the next flood-tide; and so oscillates backwards and forwards until finally dispersed by the waves or littoral currents. A strong fresh, by providing material for feeding the bar, may thus actually assist in diminishing the depth of water over it and deteriorating the channel.

An examination of the statistics relating to the bar of the Mersey will show that heavy land floods have operated in the way described, and have been followed by a decrease in depth of water on the bar. The upper estuary consists of a wide expanse of shifting sands, which are constantly being moved about owing to the changes in the position of the channels, due principally to large land floods. These changes in the sands, locally known as "frets," load the water flowing through them with sand and alluvium, which gradually travels downward, causing the ebb current to reach the bar loaded with detritus. The great fret of 1870 is reported to have caused the removal of nearly 6,000,000 cubic yards of sand out of the upper estuary. Following this the depth of water on the bar gradually diminished from 11 to 7 feet, recovering again as the cause of deterioration was removed. A decrease in depth has always followed the more important "frets" or changes which have taken place in the upper estuary.

The chief value of fresh water to tidal estuaries and rivers is in maintaining the upper reach free from deposit. There is a point, varying daily according to the height of the tide, where the flow of the tidal water ceases. At this point accumulation of deposit is apt to take place in dry seasons. This is removed by the freshets, and the tidal capacity of the river kept unimpaired.

There are bars at the mouths of channels in estuaries situated so far from the river proper that it is impossible that they can be affected by freshets. The water which passes backwards and forwards over them is always salt and, except in stormy weather, free from material in suspension. The bar at the entrance to Boston Deeps (Plate 5, Fig. 7) is 20 miles away from the mouths of the two rivers which discharge into this estuary, and the water for several miles above the bar is salt on the surface even during the heaviest land floods.

The case of Dornoch Frith is also quoted by Mr. Stevenson (Fig. 5). The bar in this river is formed of pure sand, and is situated 14 miles seaward of the point where the River Oykell enters the estuary. The magnitude of the Frith as compared to the River, the high-water area at Whitness Point being fifty times greater than at Bourn Bridge, precludes any theory as to the formation of this bar being due to the small quantity of detritus brought down by the rivers.

The bar of the Ribble (Fig. 9) is 12 miles away from the end of the trained channel. The estuary has an area of over 57 square miles, is 16 miles across where it joins the Irish Sea, and the rise of spring-tides is 27 feet 6 inches. It is impossible that the fresh water, coming off a drainage area of less than 900 square miles, can have any effect in the existence or maintenance of this bar.

As to the existence of bars being due to the way in which the channel of the estuary joins the sea, there can be no doubt that the form of the junction has an influence in the maintenance of a bar, inasmuch as it affects the force of the scouring agency of the ebb current, but this cannot be set down as the cause.

An estuary which discharges on a low flat coast at right-angles to the direction of the tidal current in the ocean is disadvantageously placed for keeping its entrance clear. The difficulty is further increased when the water has to find its way to sea across a beach encumbered with sand, as is the case all along the east side of the Irish Sea, where the tidal currents have continually to contend with an immense mass of moving material liable to be displaced and thrown across their channels at every gale.

A bar will invariably be found at the mouth of an estuary discharging into a shallow bay where the tide runs more slack than in the offing. An example of this may be found in the Tees, which discharges into a shallow bay on the east coast, and where a sandbank, having only 3 to 7 feet of water on it at low-water, existed previous to the training-works now being completed.

On the other hand, where the outfall is at the head of a deep bight, gradually increasing in width and depth towards the ocean, the conditions are unfavourable to the formation of bars.

Where there is a prominent projection in the coast-line, the tide runs round it with considerable velocity, causing great scour and deep water. An estuary discharging at the back of such a projection will be free from a bar. The outfall of the Humber is an illustration of this (Plate 5, Fig. 7). The tide coming from the north washes round Spurn Point into the estuary, the force of the flood and ebb current being sufficient to cope with the great amount of deposit always being moved about in this estuary.

The estuaries of the Thames, the Humber, and also the Wash (Figs. 1 and 7), have each a projecting coast-line on the lower or opposite side to the direction from which the tide comes. The outfall of the Seine (Fig. 6) is situated in the bight of a bay having a considerable projection on the east side, past which the tide sweeps across to the mouth of the estuary. The Scheldt discharges on a low, flat coast, where the rise of tide is small. The Shannon (Fig. 4) has two natural projections, which guide the tide directly into the estuary, which gradually decreases in width. The Forth too (Fig. 3) has, on the side from which the tide comes, a projecting headland. This estuary also gradually decreases in width. The Severn estuary (Fig. 2) is situated in a direct line with the tidal stream; it gradually decreases in width, and the rise of tide is very great. None of these estuaries have bars.

The Mersey estuary (Fig. 9) lies rather embayed behind a projection of the coast on the side from which the tidal currents flow.

The Ribble (Fig. 9) discharges on a sandy estuary in the middle of a large bay. The estuaries of the Tees and the Tweed are both embayed. Dornoch Firth (Fig. 5) is embayed, and this estuary has a very wide mouth compared to its length, and is encumbered with sands. The Tay (Fig. 3) is embayed, and has the coast on the opposite side to the direction of the tide projecting. In all these cases there are bars.

The depth of the ocean at the point of outfall has also been ascribed as having an influence on the formation of bars. Great depth increases the scouring action and diminishes the effect which the waves have in disturbing the sand. There can be no doubt that shallow water is more favourable to the maintenance of bars than deep water. The want of depth of water alone, however, is not sufficient to account for their existence any more than the configuration of the coast-line, although both these have a material effect on their maintenance.

Insufficiency of back-water.—This, no doubt, is an important element in the maintenance of bars. Reclamation and works that tend to diminish the quantity of tidal water entering and leaving an estuary must have a material influence in decreasing the effect of the scouring action of the tidal currents in moving sand washed across its mouth. On the other hand, by training a channel through a sandy estuary and dredging out hard material, a larger volume of tidal water is made to concentrate its energy in dispersing the material of the bar. The water which flows over the sands of an estuary to and from the sea, without entering the channel, has no effect in scouring and maintaining either the low-water channels or the bar; but for a considerable distance on either side of the channel the water flows off the sands into it; and the creeks off the sands and marshes continue feeding the main channel at low-water until the return of the tide.

The velocity of a current being in proportion to the square root of the depth, it follows that at high-water, when the sands are covered, the velocity of the water in the main channel must be greater than that flowing over the sands or foreshore. If the water in the main channel flows faster than that on the sands at either side, a depression must occur into which the water from the sides flows. If the banks or training-walls at the sides of the channel are carried up to high-water mark, no lateral water can get into the channel. The lower the walls are, the greater is the quantity of water that flows off the sides, and also down the channel, and consequently over the bar.

The higher the walls are carried, the greater will be the accretion.

at the back of them. On the other hand, experience has proved that low walls produce considerably less scouring effect than those carried to a moderate height; also they are not effectual in maintaining a deep low-water channel, owing to cross currents and the sand washed off the sides by the lateral currents. A mean has, therefore, to be struck between undue accretion and walls kept too low to maintain an efficient low-water channel. No fixed rule can be laid down as to what this height should be. A knowledge of the particular condition of the estuary to be dealt with can alone determine this. Walls carried to neap-tide level will have the greatest scouring effect in the first instance, but, by producing too great an amount of accretion, will ultimately diminish the area of tidal water. Generally, it may be taken that the maximum height to which training-walls should be carried in the upper part of a tidal estuary is that of half-tide level, or a mean between low-water and high-water of spring-tides, in the lower part of the estuary into which the channel to be dealt with discharges; and that they should gradually diminish in height as they approach the outfall.

The effect of training-walls is not necessarily to decrease the tidal capacity of the estuary, or to affect its scouring action on the bar. Training does not create sand, nor produce additional material. It may be the means of arresting some of the alluvium brought down by the river, which otherwise would have been carried out to sea; but this will be fully compensated for by the increased volume of water gained by the deepening of the channel. The training of the channel, and consequent raising of the foreshore, may also be the means of checking erosion which has been acting on the shores. Accretion goes on very slowly after a certain height, and when this is attained the sands become coated with slime and vegetation, and are less liable to be acted on by the winds, and to be mixed with the ebb off the foreshore and carried into the channel.

The effect of fixing the channel in one position is to prevent the constant disturbance of sand, which is transported from one part of the estuary to another; but once this sand is removed, it remains fixed. The accumulation in one place is compensated by denudation in another. It is simply, as stated by Mr. Stevenson, a "new disposition of materials." The general condition of the estuary is meanwhile improved, as the water is less encumbered by masses of moving sand, which formerly were always falling in the channel, the energy of the tidal currents being wasted in moving this sand and opening fresh channels, instead of operating to deepen and maintain one constant low-water channel.

Reclamation of land in an estuary, and the consequent diminution of its capacity if it results in the exclusion of tidal water, which feeds the main channel and exerts a scouring influence on the bar, is no doubt prejudicial. Several instances can be quoted where injudicious reclamation has resulted in the deterioration of the bar and of the outfall generally. This has been notably the case in the Dee, where reclamation was made the sole object. In this river a straight wall, 8 miles in length, was carried up above high-water level, and thus cut off all access from a large portion of the estuary to the new channel, excluding the tidal water from an area of about 7,000 acres, which previously had drained into the old channel. In Rye Harbour, the enclosure of a large tract of marsh land deprived the harbour of its back-water. The ebb current consequently became too feeble to remove the sand and shingle washed in by the waves. An accident to these works, occasioned by an extraordinary high-tide, allowed the tide again to flow up its old course for a distance of 15 miles, and so strengthened the ebb as to restore the channel to its former condition. The reclamation of a large area of land in Wexford Harbour resulted in the shoaling of the water over the bar. Mr. Rennie, in his report on Yarmouth Harbour, quoted the cases of Conway, Aberystwith, and New Shoreham, which deteriorated owing to sandbanks being lodged at their entrances, after the abstraction of tidal water by reclamation works.

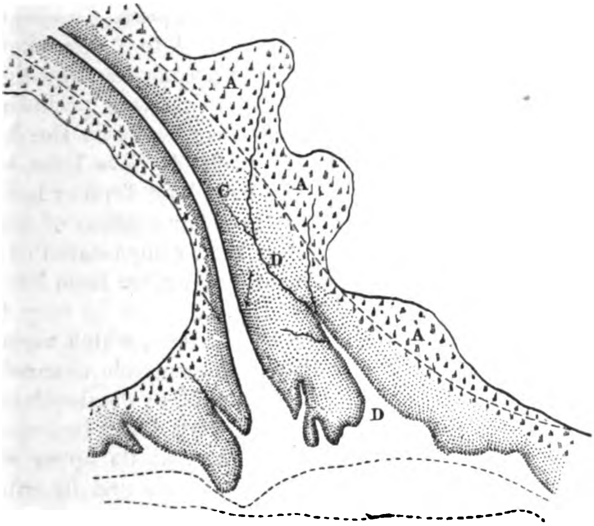
It would, however, be a mistake to condemn reclamation works in an estuary as being under all circumstances prejudicial to the preservation of the low-water channel. The rivers which have the best natural deep-water channels are those where the form of the estuary is funnel-shaped, gradually decreasing in width and shoaling as it extends upwards. In a wide, irregular-shaped estuary, by excluding the tidal water off the wider portion, and from indents and irregularities in the coast-line which retard the flow of the water, the form may be so improved as to conduce to the free flow of the tidal wave into the upper reaches. Such enclosures would not injuriously affect the maintenance of the main channel, as the water which had previously flowed over the enclosed land probably never entered it, nor passed over the bar, but assisted in keeping open a number of subsidiary creeks, which tended to set up cross currents, or to divert the tidal water from the main outfall.

The form of estuary most conducive to the preservation of the main channel in the estuary is where the surface slopes gradually from the coast to the centre, and where all the creeks trend towards and discharge into one channel.

The vital point for consideration is not the mere retention of water-area, but the preservation of all that part of the estuary the water from which has a direct influence on the low-water channel and the bar. A long length of tidal run up a defined and deep channel, is of far more value than area of estuary. In the one case, the whole of the tidal flow passes up and down in one course, and over the bar; in the other, a very large percentage passes in and out of the estuary without ever entering the channel, or having any influence on the bar.

In an estuary like that shown in *Fig. 1*, the enclosure of the marsh at A would improve the form by cutting off indents and irregularities in the coast-line, and leaving the widening out of the estuary towards the sea gradual and regular. The enclosure of these indents A A would only exclude tidal water, which finds its way to sea over the sands, or by the creeks D D; the keeping open of which might lead to the splitting of the outfall channel into two parts at C.

Fig. 1.



In the Humber, by the enclosure of nearly three-fourths of the whole estuary at different times, its form has been improved, and the outfall maintains a deep channel without the existence of any bar. Nearly 70,000 acres have been reclaimed from the Wash since the construction of the Roman banks, without creating any bar in Lynn Deeps, or, as far as known, diminishing the depth of water there or over the bar of Boston Deeps. The reclamation made along the shores of the rivers emptying into the Wash, the Ouse, the Nene, the Welland, and the Witham, having been accompanied by works of training and deepening, the navigable depth in all these rivers is greater than it was when the tidal water flowed all over the land which is now enclosed. In the Tay, from surveys made in 1887, Mr. D. Cunningham found that, although the tidal area had been diminished by accretions in the upper part of the estuary, yet, owing to improvements in the channel, the volume of tidal water had been increased and intensified in action; the channel had improved, and the depth over the bar increased. Extensive reclamations have been made in the estuary of the Tees (Fig. 14), where upwards of 2,600 acres have already been enclosed, and a large area is rapidly becoming ready for enclosure. In this estuary the training-walls have been carried from 4 to 7 feet above low-water. These reclamations having been accompanied by the training and deepening of the river, have in no way prejudiced the maintenance of the channel, or acted injuriously on the bar. In the estuary of the Ribble, it would probably have been better if the enclosures at the upper end had been kept further back, so as to have allowed a wider foreshore for the reception of the tidal water, although the loss of area has been compensated to a large extent by the training and deepening the river from Preston to the Naze, a distance of 4½ miles. But it would be very difficult to show that enclosures along the south shore, which varies from 1½ mile to 3 miles from the central and navigable channel, could have any effect in maintaining this channel, or the depth of water over the bar, but rather otherwise; it may fairly be argued that by contracting this great width of estuary at its upper end, the water which now flows to sea over the sands and by subsidiary channels would, as a consequence, be diverted into the central channel. In the Mississippi, the training of the South-West Pass has resulted in the deepening of the channel by natural scour to a very large extent, although this training has been the means of accretion to a height of about 16 feet at the back of the walls, and the space formerly occupied by water is now covered with grass.

The theory that bars are due to the difference in duration of the ebb-tide and flood-tide, and the slope of the water, was put forward by Mr. W. A. Brooks in his Treatise on the improvement of the navigation of rivers, published in 1841, who claimed this as a new discovery. Bars, he states, are always found in rivers where the slope is greater near the ocean than in the upper reaches, and where the duration of the ebb is longer than that of the flood. The formation of the bar he ascribes to the deposit of sand or other material held in suspension by the ebb-current, caused by the action of the flood-tide, which, by reason of its greater specific gravity, forces its way up under the ebb in a wedge form, checks its velocity, and causes it to yield the matter in suspension. The bar, he considers, is thus formed during the first part of the flood-tide; the direct tendency of the ebb, which is of greater duration than the flood, when unobstructed by the flood being to reduce the bar. If this theory were correct—and if, as further stated by Mr. Brooks, the ebb-current has the greater influence owing to its longer duration than the flood—it ought to be of sufficient power to remove the deposit left during the first of the flood. That this cause is not sufficient to account for the existence of bars is shown by the fact that in many rivers or estuaries where the duration of the ebb and flood is nearly the same, and the inclination in the lower reach of the river considerably less than in the upper reaches, perfect specimens of bars exist.

Scouring effect of the Ebb-tide and Flood-tide.—Differences of opinion exist as to the relative effect of the flood-tide and ebb-tide in its scouring action on the bar. In the upper part of an estuary, the ebb-tide lasts considerably longer than the flood. At the lower end the time is more equal, but generally in favour of the ebb. As the quantity of water that enters an estuary each tide is the same as that which passes out, it is contended that the velocity of the flood must be greater than that of the ebb; and that the velocity being greater, the scouring effect must be greater. This theory appears to be founded on a wrong assumption of facts.

Supposing the tide takes five and a-half hours to enter the estuary, the ebb will have six and three-quarters to flow out. But the greater bulk of the water will have passed out in considerably less time than this, and for the last two or three hours the only water passing seaward will be that from the low-water channels, occupying a very small portion of the estuary. The difference in the velocity due to the difference in time is therefore very slight. The energy of all the first part of the flood-tide is expended in overcoming the resistance it meets with on its way up the channels. It has not only to stop, but to reverse the action of the ebb-current. The surface-current becomes reversed some time before that at the bottom, and there is a period when, although there is a strong current at the surface, there is little or no motion at the bottom. This has been proved by the observations of Messrs. Humphreys and Abbot in the Mississippi, and also by those of Mr. W. R. Browne in the Severn.[1] As the tide rises, and the water begins to cover the sandbanks, it has also to overcome the resistance due to gravity, the friction of the particles of the water against the sandbanks, and the power required to roll the particles of movable sand upwards. At high-water there is a period of slack, and the ebb has not therefore to spend its energy in reversing the action of the current. Its whole power is effective from the time that the reverse movement has extended throughout the whole mass. As the water falls off the sands, gravity is acting with, and not against it, and until flood-tide makes its scouring action is continuous.

If the flood had a largely predominating influence, these estuaries would have been filled up many centuries ago by the material driven into them, if on the other hand the force of the ebb was largely in excess, they would always be deepening and increasing in size. As however their general status is maintained over long periods of time, it is evident that the two forces of the tidal ebb and flood are nearly evenly balanced, the ebb having just so much preponderance as enables it to carry away and dispose of the detritus brought down to the estuary by the upland waters.

The time when the current probably has its greatest scouring effect is from the beginning of the second quarter ebb to the beginning of the last quarter. During this period the tide falls nearly twice as fast as during the first and last quarters.

The scouring power of the water is a compound force depending on velocity and weight. The scouring effect is therefore at its greatest when the depth of the water and the velocity combined are at their maximum.

The action of water in removing heavy detritus is to roll it along the bottom. Sand is never found in suspension at any distance from the bottom except after great disturbances caused by storms. The material transported into an estuary is rolled backwards and forwards with every tide, advancing or retreating according to the strength of the ebb current as affected by spring-tides or neap-tides, or by gales blowing from one or the other direction, but always ultimately progressing downward.

Bars caused by the Action of the Sea.—Having dealt with the theories which ascribe the existence of bars to the action of the ebb current, there remains now to be dealt with those of which the cause can be traced to the action of the sea. Two centuries ago the Abbot Castelli expressed the opinion that the obstructions

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[1] Minutes of Proceedings Inst. C.E., vol. lxvi.

to the entrance to the ports on the Mediterranean proceeded from the violence of the sea, which threw up a body of sand of the shape of a half-moon at the place where the river fell into the sea. Another theory was put forward by Colonel Emy as given by Mr. Brooks to the effect that the bar is due to the action of the bottom waves, which, having traversed the shore, present themselves directly to the mouth of a river, and in tempests carry with them sand which is deposited in banks. If the bottom is irregular and a slope exists at the mouth, these "ground waves" rise on encountering the obstacle, and being no longer able to continue their course under the tidal stream, because their movement ceases to be in harmony with the undulation, they are met and dispersed by the current of the river. During the moment of repose while their waters mix with those of the river, the sand which they held is precipitated, and quickly thrown above the declivity by the succeeding ground waves. This sand forms the bar, which increases rapidly in stormy weather. Geologists, as represented by Sir H. T. De la Bêche, ascribe the formation of bars to the action of the winds on the coasts, which cause the detritus to be piled up by the waves in the direction of their greatest force. Captain Calver also attributed bars to the action of the on-shore waves, the crests of which, being impelled forward at a greater rate than the foot, the summit arrives at an overhanging position whence it descends, and by the impetus acquired pushes forward the mass of water directly before it. The effect of this downward stroke is to charge the wave with the material composing the bottom. When this occurs on the shore the drawback or undertow carries the material with it; but where a break occurs in the continuity of the coast line, as at the mouth of a river, the successive strokes are followed by the movement of a stream of particles in a direction obliquely across the entrance, which would thus become a permanent obstruction but for the flow and reflow of the tides. "The evidence of this struggle is the bar which is the balance of power between the two forces, that of the sea to heap up material and close up the river on the one hand, and the reflow of the tide with the land water to scour the impediment away." Mr. D. Stevenson, in his work on river engineering, also attributes the formation solely to the action of the waves of the sea, in throwing up round every bay and headland on the coasts a girdle of light or heavy material, varying with the exposure from sand to boulders, to which the entrance to rivers forms no exception, and thus a continuous line of beach is formed across the mouths of tidal estuaries. He summarises the conditions necessary to the formation of bars thus:—1. The presence of sand or shingle, or other easily moved material. 2. Water of a depth so limited that the waves during storms may act on the bottom. 3. Such an exposure as shall allow of waves being generated of sufficient size to operate on the submerged materials.[1] Mr. I. J. Mann, in his book on "River Bars," agrees with Mr. Stevenson in ascribing their formation to the action of the waves. Mr. Vernon-Harcourt, in his "Treatise on Rivers and Canals," says: "The tendency of the sea, or of waves driven along the shore by prevailing winds, or of littoral currents," is "to heap up the beach in a continuous line along the shore, and close up the outlet of the river, which is only partially prevented by the scour of the tidal ebb and flow, and the discharge of the inland waters."

It appears to the Author that this is a correct definition of the cause of bars, and he entirely agrees with those authorities who ascribe their existence to the action of the sea, and to on-shore gales as the chief factors in their maintenance. Gales, however, are only occasional, and their continuance is not long enough to account for the transport of material along the coast.

Bars, having been produced when the coast-line and estuary assumed their original form, owe their continuance to the balance of forces between the ebb and flood currents, and are maintained without material alteration under normal conditions, and until some disturbing cause gives a preponderating influence to one of the contending forces. If the material supplied by the flood current depended solely on causes operating in stormy weather, the bar would diminish in summer, when frequently there is a long continuance of calm weather, and increase when gales are most prevalent. In many cases alterations are stated to take place under such circumstances; but in the longest calms a bar never disappears, and where the shores extend out beyond the line of the bar it remains unaltered even in stormy weather.

The chief effect of gales is in eroding the cliffs, and in loosening and breaking up the beach. The material thus liberated is carried forward by the littoral current. The travel of material is always in the direction of those winds which have most effect on the coast. On-shore winds, even when moderate, must therefore be agents in the transport, but the tidal currents have even greater influence. The flood current, pushing its way along the shore, cuts into the sand and drives it along before it, ultimately dropping it over the bank into the deeper water of the outfall channel.

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[1] "The Principles and Practice of Canal and River Engineering." 3rd edition, 1886, p. 312.

The effect at spring-tides is greater than at neaps to the extent of their higher rise and more effective scouring power. This action, taking place twice every day, would keep up a continuous supply of material, were it not that the beach becomes denuded, or the sand or shingle so settled that the current does not affect it until again broken up by the force of the waves in gales. The ebb current being as long in duration as the flood may roll some of the material back along the beach on the return tide, but has not sufficient force to lift that portion of it which has been washed into the mouth of the estuary up the sides of the channel on to the beach again.

An an example of the action of travelling material on the outfall of a river, the case of the River Adur on the Sussex coast may be quoted. The travelling shingle, moving along the beach from the west, drove the mouth of the river 4 miles eastward from its original course. The outfall of the River Yare, on the Norfolk coast, also has been diverted southward nearly 3 miles from its original outfall, by the sand travelling along the beach from the north, and its progress was only arrested by works carried out for the purpose of preventing the sand from further encroaching on the outfall.

A tidal bar assumes the form of a ridge, having deep water on either side. This ridge form probably owes its shape to the action caused by the meeting of the ebb and the flood currents at the point where the effect is at its maximum. At the point of collision the lower films of water are deflected upwards, the detritus rolled along the bottom being thus headed up and forming a bank. The continuance of the ridge is aided by the rotary motion of the water, the individual particles of which roll round one another in their forward motion, imparting a tendency to the whole mass to assume a curved course rather than one parallel to the plane in which it is moving. The form which a sand bar generally assumes is that of a flat slope in the direction in which the current is running, with a steep face on the downstream side. The heavy particles of sand are rolled by the current up the slope and over the ridge, the form of the slope and action being reversed on the turn of the tide.

Even in the junction of those estuaries with the sea where, owing to the great depth, no bar that forms an impediment to the navigation exists, the bottom assumes the form of ridge and depression. For example, in the Seine below Havre a depth of 38 feet at low-water is succeeded by a narrow ridge with a depth of water on it of 27 feet and a depression on the lower ridge of

46 feet. Then a ridge with a depth of water of 32 feet, whence it deepens again.

The conditions most favourable to the absence of bars are those where the estuary assumes a funnel-shaped form, gradually decreasing in width and depth from the mouth upwards, with a small inclination of the bed and long tidal run. An estuary having its widest part at the mouth gradually decreasing upwards allows of a free entrance of sufficient tidal water to fill the upper reaches.

The greater the depth of water at the mouth of the estuary, and the further the depth is maintained up the river, the more favourable are the conditions for the propagation of the tidal wave, and the greater the quantity of water that will pass into and out of the river at each tide.

As an example of rivers having long tidal runs and gradually-decreasing widths, the Thames, the Severn, and the Humber may be quoted. Each of these has nearly the same length of tidal run, and their estuaries decrease nearly in the same ratio. Thus the length of tidal run from Southend is 62 miles, and the estuary from there to London Bridge decreases at a mean rate of about 0·10 mile for each mile in length. The Severn from Western Point has a tidal run of 65 miles, and decreases at a mean rate of about 0·19 mile. The Humber with a tidal run, including the Ouse, of 65 miles, decreases from Spurn Point to the junction of the Ouse at a mean rate of 0·17 mile per mile.

WORKS FOR THE REMOVAL OF BARS.

The existence of bars in tidal estuaries is thus due to a struggle between the waves and littoral currents engaged in piling up material carried into the estuary by the flood-tide, and the ebb current in removing the same; it is obvious that, in designing any works for their removal, the object to be kept in view should be the disturbance of the existing balance of forces by increasing the depth of water at the outfall and the power of the ebb current. The greater depth of water is required to neutralize the action of waves and for the dispersal of the material carried across the mouth, and the increased power of the ebb is necessary for making the scouring greater than the accumulating force.

The most successful way in which this has been accomplished has been by concentrating the full force of the ebb current on that part of the estuary where the bar exists.

On the Tees (Figs. 14 and 15), by confining the low-water channel to one course, by deepening it and thus increasing the tidal capacity, by constructing a sea-wall across the south side of the estuary and thus concentrating the full scouring power of the ebb current at one point, the bar which previous to the construction of the breakwater and training-walls was continually shifting its position, and had a depth of water on it varying from 3 to 7 feet at low-water spring-tides, giving an average depth of about 24 feet 6 inches at high-water, has now an available depth of 36 feet. The whole of this has been accomplished by scour, no dredging having been done near the bar. A description of the works carried out for the improvement of this river will be found in a Paper by the late Mr. J. Fowler (of Stockton).[1]

The same result has followed the works for the improvement of the Liffey at Dublin (Fig. 16). In this estuary a wall was carried out on the south side extending for 3 miles in the direction of the low-water channel, and also a wall on the north side extending out from the shore a distance of 9,000 feet, converging towards the south wall, leaving an opening of 1,000 feet in width. A tidal basin has thus been formed 2,350 acres in extent. The average quantity of water flowing in and out is estimated at 30,000,000 tons each tide, the capacity above half-tide level being 19,000,000 tons. The Great South Wall, which was finished in 1796, was carried above the level of high-water, and when first completed had the effect of protecting the river from the encroachments of the South Bull sands, confining the ebb and the flood currents in a more defined channel, and slightly improving the bar. The north wall was not completed till 1819. For about one-half its length next to the shore the top is 6 feet above high-water; it then drops to the level of high-water; and thence gradually slopes down, the entrance end dropping below low-water. The effect of this work, accompanied by the improvement of the channel between the Poolbeg Lighthouse and Dublin by dredging, has been to increase the velocity of the current from 1¼ mile to 3 miles an hour. The increased scouring action lowered the bar 5 feet in the first ten years. The deepening has since continued, although at a less rapid rate, the total gain having been 12 feet. Before the erection of the Great North Wall, the depth on the bar was 6 feet at low-water and 19 feet at high-water; now it is 29 feet at high-water of spring-tides. Inside the harbour the channel has deepened by scour from 8 feet to 14 feet 6 inches, giving 27 feet 6 inches at high-water for a length of about 1,000 feet. Immediately outside

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[1] Minutes of Proceedings Inst. C.E., vol. xc. p. 344.

the walls the channel has deepened from 14 feet to 29 feet over a length of about 2,000 feet. The shoalest part of the bar is about 3,500 feet from the end of the walls, with 29 feet at high-water. The scouring action appears to have ceased at about 1 mile beyond the end of the walls, the depth there being now the same as in 1819, 16 feet. At 1¾ mile it deepens to 23 feet, and at 2 miles to 30 feet. An account of this work, with plans and sections of the channel, will be found in a Paper by Mr. J. P. Griffith, read in 1879.[1]

In the Tyne (Figs. 12 and 13) the water over the bar has been deepened from 6 feet to 22 feet 6 inches, and the navigable channel lowered to correspond, giving a depth of 37 feet at high-water of spring-tides. This has been accomplished principally by dredging. Sand and other material, amounting to about 83,000,000 tons, have been removed and carried out to sea. The construction of the sea-walls, which was commenced in 1856 by increasing the scouring agency of the ebb and by checking the travel of sand by the north wall, has had a material effect in assisting to deepen and in maintaining the improved channel. The width of the dredged channel is 670 feet. The two walls gradually converge towards each other, the north wall extending over 3,000 feet at the present time, and the south wall nearly 1 mile, forming a large tidal basin between them, which, with the deepening of the channel, affords an increased tidal capacity. The opening at the entrance where the works are finished is intended to be 1,300 feet.[2]

Captain Calver[3] has expressed the opinion that it is useless to project piers at the mouth of an estuary merely with the view of getting beyond a bar, as wherever the outer ends of these works are placed, unless they are so designed as to store up and concentrate the tidal water, the bar will form again in front of them. The great object, he states, to be achieved in the erection of piers should be to secure the preponderance of the inner power as the most effectual means for keeping the obstruction at the lowest possible level. This, he contends, can only be accomplished by carrying the piers out into deep water, and so designing them that they shall operate in concentrating the scour of the ebb. If the piers are carried out into sufficient depth the action of the waves in throwing up sand from the submerged

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[1] Minutes of Proceedings Inst. C.E., vol. lviii. p. 104.

[2] "River Tyne Improvement," by P. J. Messent, C.E.

[3] "Conservation and Improvement of Tidal Rivers," 1853.

beach in front of them would be stopped. He advises that as far as practicable piers should be run out in such a position as to form promontories projecting from the general run of the coast-line so as to avoid the effect of slack water and secure the full force of the tidal currents.

The accumulation of sand at the piers which have been made for the improvement of Calais and Dunkirk harbours, on the north coast of France, confirms this view; as does also the case of the River Adour where it enters the Bay of Biscay. The outfall of this river is on a shallow sandy foreshore, with a rise of tide of only 8 feet at spring-tides. Piers were carried out along both sides of the outfall in order to contract the entrance with the intention of scouring away the bar of sand at the mouth. The only result of this work was to push the bar further seaward. Subsequently the piers were extended by walls having solid bases with openings left above; the object of this formation being that while the solid base stopped the travel of sand, the openings would allow the littoral current to flow across the channel. The result of this work was a deepening of water over the bar of 3½ feet, but the progress of the foreshore was not permanently arrested. The harbour of Lowestoft, situated on the flat shores of the East Coast, has been formed by piers built out into the sea. The North Pier has acted as a groyne, causing the sand to accumulate at the back of it, and which now extends more than 1,000 feet from the original face of the shore. Although these piers enclose a large area of tidal water, yet owing to their not forming a sufficiently prominent projection by being carried to deep water, they do not prevent either the travel of the shingle or increase the velocity of the littoral current. The entrance to the harbour is therefore frequently blocked up by the shingle and sand travelling round the pier ends, and this material, which sometimes amounts to as much as 200,000 tons in one year, has to be dredged out.[1]

The piers of the Tees, the Tyne, and the Liffey (Figs. 12, 14, and 16), and those now being carried out at Sunderland, conform with the views laid down by Captain Calver. They extend from the coast-line in the form of promontories. They project sufficiently to reach such a depth of water that solid material is not thrown into the harbour in gales, and the large area of tidal basin secures an efficient scour.

As the chief object to be attained in the disposal of bars is the

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 182.

prevention of the material composing them travelling along the beach from being carried into the mouth of the estuary, a single wall, carried up sufficiently high to arrest the progress of the sand or shingle, may on some coasts be sufficient. This wall would have to be placed on the side of the channel from which the littoral currents and prevailing gales come; be carried out into deep water; and be concave in form, with the concave side next the channel. The wall would act as a groyne in stopping the material from being carried to the bar. The flood current having to work along the convex side and round the projecting end, would keep it scoured. The ebb current from the estuary would always have a tendency to keep along the concave side, and thus maintain deep water along the wall.

Attempts have been made to remove bars by stirring up the material of which they are composed and leaving it to be removed by the transporting power of the ebb current. As far as the Author is aware, these attempts have been confined to non-tidal rivers, or to those in which the ebb due to the land-water predominates over the tidal influence. An account of the successful removal of a bar composed of sand and gravel, at small cost, by the use of the propeller of a steamer moored over the site of the bar, has been brought before the Institution.[1] The Author is of opinion that under certain conditions bars in tidal estuaries can be dispersed by breaking up and disintegrating the material if compact, or by stirring up and mixing with the current if composed of sand; and leaving the water to transport it into the deeper parts of the channel. If the depth of the channel was by this means materially increased, the bar probably would not form again; even if it did re-form, the cost of removal by this means would be so small as compared with the advantage gained, that it seems desirable that steps should be taken to ascertain the practicability of this course.

CONCLUSIONS.

From the facts and opinions given in this Paper, the Author considers that he is justified in stating—

1. That the causes which operate in maintaining the existence of bars in tidal estuaries come from the sea, and are not due to the inland water.

2. That the dispersal of bars, and the improvement of the outfall channels of estuaries, can be accomplished by increasing the volume

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxiii. p. 386.

and velocity of the tidal water passing over the bar, and by giving a greater preponderance to the ebb current.

3. That in designing works for this purpose the circumstances of those estuaries which have natural deep-water channels free from bars should be taken as guides.

The lessons to be taught by an examination of estuaries having natural deep-water channels are—(*a*) That the mouth of the outfall should be capacious enough to allow of the entry of sufficient tidal water to fill up all the estuary and upper reaches of the river; (*b*) that to ensure a regular and undisturbed flow the form of the estuary should be such as to afford a gradually decreasing width from the outfall; (*c*) that the depth of water in the channel should be sufficient to allow of a free propagation of the tidal wave; (*d*) that the longer the run of tidal water that can be given the more effective will be the scouring action, and that therefore all obstructions to the free flow of the tidal current are prejudicial to the outfall; (*e*) that it is essential to secure adequate depth of the channel by natural scour or by dredging; (*f*) that training and fixing in one position the low-water channel in a sandy estuary is of first importance in securing the full advantage of the tidal scour, and in maintaining a deep channel; (*g*) that water flowing in and out of an estuary which does not pass to or from the sea over the bar, and by the main navigable channel, is of no advantage to the outfall, and is better excluded; therefore, while it is of the utmost importance to conserve an estuary as a receptacle for the tidal water, the exclusion of such water from indents, and the cutting off of irregularities by embankments, may be carried out without detriment to the outfall.

4. That piers carried out from the shore are useless unless extended to deep water.

That they should be so designed as, while not unduly throttling the inflow of the tidal water, they should effect the greatest amount of scouring force from the ebb current.

The Paper is accompanied by three tracings, from which Plate 5 and the *Fig.* in the text have been engraved.

Discussion.

Mr. Vernon-Harcourt.

Mr. L. F. VERNON-HARCOURT said that the Author had referred to the Mississippi as a case where a bar had formed; but care should be taken in distinguishing between tidal and tideless rivers. The Mississippi, it was known, was really an example of a tideless river, and therefore he did not think it was the case, whatever Messrs. Humphreys and Abbot had said, that the bar at its mouth was due to the tide. It was rather due to the absence of any tide, because its waters brought down a large quantity of alluvium, and deposited it in the slack water, where there was practically no tide to carry it to and fro. Reference had also been made to rivers not silting up; but he thought there were certain rivers, which, although they did not entirely silt up, owing to the fresh water flow, yet were in process of silting up, like some small rivers flowing into the North Sea, which by degrees, partly, possibly, owing to unwise reclamations, but also partly owing to accretion due to sand coming in, had to some extent silted up. He referred to such ports as Calais, Gravelines, Dunkirk, and Nieuport,[1] which originated from the small rivers that flowed into the sea forming creeks. The Author had stated that the outlet-channel of the Seine was always provided with deep water like the Thames, but that was not really quite correct, because it was impossible to navigate the Seine at low-water. Last year, during the excursions of the Congress on the Utilization of River Waters, he had gone to Havre, and went up the Seine, in a small steamer, with the Congress and the French Minister of Public Works; and they had to wait until the tide had risen a certain amount before they were able to enter the estuary, and even then, owing to the change of the channel, they had to go nearly as far as Trouville before entering the channel. He thought the Author had hardly given enough credit to the influence of the fresh water of a river in maintaining its channel. Of course, as compared with the tidal water, in the case of the Thames, Humber, and many other rivers, fresh water had very little influence below, but it had the advantage above of keeping the channel open, and scouring it during the latter part of the ebb. As was well known, floods going down rivers did tend to scour them out. He might

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[1] Minutes of Proceedings Inst. C.E., vol. lxx. pp. 3, 5, and 9.

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mention the case of the upper tidal portion of the Yorkshire Ouse, which came under his notice last year. The river was continually silting up in the summer, and thereby diminishing greatly in depth from Naburn Lock nearly down to Selby, owing to the deposit, in the absence of fresh water, of the warp that came up from the muddy Humber; but it was scoured out again by the winter floods. Even in the case of the Mersey, the fresh water was of some advantage in scouring out the upper estuary. He thought that the Author agreed with the general view that the ebb-tide from the wide upper Mersey estuary did help in scouring the channel over the bar; and he was not at all sure that the great fret, about which a great deal was heard before some parliamentary committees some years ago, was not an advantage to the estuary of the Mersey, because it carried down the sand and cleared out the upper estuary, increasing its tidal capacity; though possibly, but he did not think that it was proved, some of the sand from the upper estuary did deposit for a time on the bar, which was eventually lowered again by the improved scour from the upper estuary. With regard to the Ribble, last summer he got stranded in mid channel for a short time, near low-water, in a small boat, on one occasion a little above Lytham, and a fortnight later about 4 miles from the bar. The bar there, he thought, was not 12 miles from the trained channel, unless the Author meant the channel which was trained on both sides of the river, because the training-walls extended something like 1¼ mile, or even more, below Lytham, and the bar was certainly not more than 6 or 7 miles below the end of the southern training-wall. Then mention was made of Wexford Harbour, which Mr. Vernon-Harcourt knew very well a few years ago. There, undoubtedly, the Author was right in attributing the deterioration of the harbour to large reclamations. It was a kind of lagoon harbour, only partially maintained by the River Slaney. At least half of the lagoon had been brought into culture, and therefore the scouring effect of the sea-water going in and out at each tide had in a great measure been reduced. As to the Author's statement about the improvement by training-works being due to the increased run of the tide, account should also be taken of the area which the tide covered; because really the improvement was due to the increased volume of the tidal flow, and not merely to the increased depth of the channel. If the area could be increased, then the tidal capacity would be improved; but to increase the depth very much below low-water only aided the tide to a small extent in coming up by reducing the friction;

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and even harm might be done in some cases by restricting the channel, and diminishing in that way the tidal area, though undoubtedly in almost every case the depth of the trained channel itself would be improved. The Author also mentioned that the loss of area on the Ribble was compensated for by deepening. Mr. Vernon-Harcourt hardly thought that that had really occurred. There had been undoubtedly an increase in the depth of the Ribble in some places above Lytham; but large tracts of the estuary had been practically reclaimed, and, he thought, in a great measure to the injury, if not to the central channel of the river certainly to the channel which went towards the south; and, therefore, it seemed to him, to the injury of Southport. The Author, again, reverted to the Mississippi, as a case proving that training-works might be beneficial to the bar; but Mr. Vernon-Harcourt thought it would be better to separate tidal and tideless rivers entirely, and not to try to prove anything from a case like the Mississippi in dealing with the bars at the mouths of tidal estuaries. The two cases were so very distinct that he did not think there was any good in trying to draw an analogy between them.[1] The Author also mentioned that the water that entered and left an estuary was precisely the same. Of course it was so as far as tidal water was concerned; but there was also fresh water always coming down, which was one of the causes that helped to keep the channel open, because the ebb would otherwise have less power than the flood if it were not for the fresh water. It was well known that creeks on sandy coasts did by degrees silt up, owing to the absence of the help of any fresh water. With regard to the statement of the Author as to the equilibrium of the flood and ebb generally, and as to the trumpet-shaped mouths of estuaries being the best, he was quite in agreement with him; and, indeed, had expressed the same views in very similar language about eight years ago.[2] He thought it might be interesting to the Institution to see the results of experiments which he had mentioned during the discussion on the previous Paper, on the Liverpool Docks, as having been carried out within the last four years with models of the Seine and the Mersey. The model of the Seine formed the subject of a Paper read last year, which had been printed in the Proceedings of the Royal Society, in which would be found a full description of the method of working of that model, and the results with different schemes of

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[1] Minutes of Proceedings Inst. C.E. vol. lxx., p. 19.

[2] "Rivers and Canals," by L. F. Vernon-Harcourt, pp. 231 and 234.

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training-walls.[1] He came to the same conclusion with reference to the training-works on the Seine, that it was an advantage to have a trumpet-shaped outlet, and not to have an outlet which was irregular in form. The diagrams gave instances of the results produced, in a working model, with the principal schemes that had been proposed for the prolongation of the training-works on the Seine by different French engineers. The last one was an attempt of his own to see how far it would be possible to enlarge the width of the trained channel, so as to admit the greatest amount of tidal water; and he thought that the results shown in the diagrams pointed to the conclusion that a trumpet-shaped form was decidedly better than any other. The first diagram showed the results with a proposal of Mr. Partiot; the second diagram indicated the influence of a scheme of the late Mr. Lavoinne, who was Engineer-in-Chief of the tidal Seine; the third exhibited the effect of a scheme proposed by Mr. Vauthier, who had devoted a great deal of consideration to the question; the fourth showed the changes produced by the scheme of a commission appointed by the French Government; and the fifth was not a regular scheme, but simply an experiment of his own.[1] One good result at least had followed from these model-experiments, namely, that the French Engineer-in-Chief of the tidal Seine, Mr. Mengin, contemplated last summer making model-experiments on a larger scale at the cost of the French Government, which probably were now being carried out, with the object of discovering the best arrangement for the prolongation of the training-walls. The upper diagrams showed some model-experiments that were carried out more recently with reference to the Mersey, to ascertain the effect of training-works on the estuary. The first diagram exhibited the extent to which the existing conditions of the Mersey estuary, from Warrington to beyond the bar, could be reproduced in a small scale working model. The second showed the result of introducing the training-works that were proposed for the Manchester Ship-Canal scheme of 1884, effecting the silting up of the upper estuary, and the consequent great reduction in depth of the navigation channel below the "Narrows"; the third showed the introduction of training-works in the outer estuary, without any alteration in the sandbanks; and the fourth showed the result of putting in the same training-walls, and also performing some dredging, by removing a portion of the

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[1] "Proceedings of the Royal Society of London," vol. xlv. p. 504; plate 2, scheme A; plate 3, scheme C, and scheme D; and plate 4, scheme E, and scheme F.

Mr. Vernon-Harcourt. sand-banks. The results obtained with the Mersey model had been fully described in a Paper read before the Royal Society on the 30th of January, 1890. The Seine model was made to a scale of $\frac{1}{40,000}$ horizontal, and $\frac{1}{400}$ vertical, affording a rise of tide, by the tipping of a tray, of about ¾ inch in the model. It was carried up to the limit of the tidal Seine at Martot. The model of the Mersey was made to a scale of $\frac{1}{30,000}$ horizontal, and $\frac{1}{500}$ vertical, giving a maximum rise of tide of ¾ inch in the model. He believed that the model experiments showed that it was possible, by imitating in miniature the action of the tidal ebb and flow and the fresh-water discharge, to produce in a small model, with a bed of very fine sand, results fairly approximate to the actual conditions of an exposed estuary, indicating that these forces exercised the main influence in shaping the channels of an estuary out to the open sea. Moreover, the actual influence of existing training-walls had been reproduced in the Seine model; and, by analogy, the results exhibited in the diagrams might be regarded as those which would be produced by the various schemes, if carried out. Engineers would by this means be enabled to ascertain beforehand the probable effects of any system of training-works, and thus avoid schemes leading to injurious results, such as those exhibited in the second Mersey diagram, and to select the lines of training-walls most advantageous for any particular estuary. In conclusion, he would only add that he should feel that the time, trouble, and money devoted to these model-experiments had not been expended in vain, if these experiments led engineers to learn from nature the effects of training-walls on a small scale before introducing them into estuaries; if they removed the divergences of opinion as to the effects of training-walls under certain conditions; and if they resulted in the establishment of correct general principles for guidance in the designing of training-works through tidal sandy estuaries.

Mr. Kinipple. Mr. W. R. KINIPPLE noticed that the Author ascribed the formation of bars to the action of waves, and he also observed that Mr. Vernon-Harcourt coincided with that view; but he thought it was not altogether so. He had himself made some experiments in quiet water with small models, and a bar was formed each time possessing the same characteristics. He thought it was not necessary for waves to be driven along the shore, or to have the action of any waves whatever, to form a bar. Waves, acting in opposition to outflowing currents, did unquestionably give fantastic and unaccountable shapes to bars; but this was different from ascribing the formation of bars to the action of waves alone. In the case of

Mr. Kinipple.

entrances to small rivers, where there was a bar, very frequently they were sheltered from winds and waves; especially in inland waters, which were free of tides. Even debris forced into a heap at a mill-tail was nothing more or less than a bar. There were bars formed almost solely by waves and currents, but these were generally well out to sea, at the ends of channels, and partook more of the character of low sandbanks than of bars as generally understood. In Aberdeen, there was a bar just inside the north pier, where the exposure was to the north and north-east. During heavy weather, and strong gales from the north-east, that bar was driven up into the harbour. If there happened to be a dry season, it was driven further up the harbour; but should there be fine weather outside, and a heavy spate inside, it was shifted down nearer the sea. That was a case in point, where a bar was moved either inwards by seas, or outwards by the outflowing waters, and which had to be kept down by dredging. In February, 1868, he was engaged in laying down river-lines on the Clyde from Greenock up towards Port Glasgow. His object at that time was to carry the future Greenock Harbour Works out to those lines. These lines, with his recommendation for dredging a central channel of 200 feet in width by 23 feet in depth at low-water, and a depth of 18 feet along the sides thereof, were ultimately adopted with very slight modification by a Committee of the House of Lords, in 1880. In March 1870, he was inclined to fall in with the views of some of the authorities in Glasgow who wanted to cut through the Greenock bank, and he said:—"By all means cut through that bank, but he only expressed his approval of this, if it were done in such a way that a large bay, or tidal harbour, might be enclosed, and given to Greenock in front of the town, similar to the great harbour which he proposed and had since enclosed at Ladyburn, east of Garvel Point." The Leven and Clyde converged at Dumbarton, and from there to the tail of the Greenock bank, along the whole length of the north side, and some portions of the south side of the channel, he proposed to train or harden the margins of the channel. These banks were to be about 2 feet above low-water level, or up to the tops of the Pillar, Cockle, and Greenock banks. They were not to be training-banks as commonly formed, but simply composed of boulder-clay, or broken stone, so as to pen in the last of the ebb waters southward of such banks, and allow the flood coming in from the north side to have free swing over them into the channel. At Port Glasgow it was sometimes flood nearly half an hour earlier than at Greenock. The last of the ebb-tide came down

Mr. Kinipple. with considerable force, and was confined almost wholly to the south side of the estuary below Dumbarton. At the present time, if there was a bar at all on the Clyde, it was just above Port Glasgow, or opposite to Cardross. Fortunately for Greenock, the Clyde Navigation Trustees had kept more or less, for some twenty years in that locality, a dredger to pick up the travelling material, which otherwise would have found its way down into the Bay of Greenock; and no doubt this had effected a considerable saving to the Clyde Lighthouse Trust in dredging operations in front of Greenock, and, further, would most likely reduce the rate of growth of the Greenock bank. This bank was the property of the Greenock Harbour Trust, and it was not at all improbable that in future it might be materially reduced. Garvel Point was cut off some fifteen years ago to the extent of about 120 feet in width by 14 feet in depth in the first instance, and subsequently to 18 feet in depth and to a greater width, with a view of improving the lower part of the channel. There was before commencing operations a sectional area of about 600 feet by 18 feet in depth at low-water; and that had been the normal condition of things, taking the average section all the year round, for one hundred and fifty years. He was instructed to take off that point, and did so. It was chiefly composed of hard boulder-clay. At that time he reported, that it was of very little use spending money on its removal, except for straightening the channel; because, as the point was removed on the south side, so would the sand come in on the opposite side of the channel. After a year or two, sections were taken in the spring of 1876, verified by Messrs. Stevenson in August of the same year, and these showed that precisely what he had predicted had then taken place; for in regard to sectional area there had been no improvement. These facts were officially recorded at the time; but the present section of the channel, after more than thirteen years of dredging operations in the locality and above and below the point, might have increased its original normal section. As the Clyde Lighthouses Trust had been dredging in front of Greenock since 1876, it would be interesting to know what were the depths in the channel at the present time as compared with those of 1872, that was before any dredgings were commenced, when a survey of the channel was made. His impression was that a large amount of material along the frontage of Greenock had been dredged beyond what was necessary to obtain the agreed upon depths and widths, sanctioned by Parliament in 1880, unless the almost constant dredging by the Clyde Navigation Trust, just above Newark Castle, since 1872, had prevented the travelling silt from

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being carried down the river into the embayed area in front of Greenock. In a river like the Clyde it would be a mistake to keep training-banks high. The last of the ebb should not go by the north side to the sea, and the banks should be so trained as to give the fullest width of channel capable of being kept open by scour. In that way he believed the Clyde would have a fair channel, capable of keeping itself open naturally, and so the present expensive operation of dredging might to a great extent be dispensed with. In 1870 he estimated that more than 50 per cent. of the last of the ebb-water was lost by escaping to sea through the swashways between the Pillar and Cockle, and the Cockle and Greenock banks, and therefore these should have been blocked up. About three years ago he had reported on the bar at the mouth of the small harbour of Irvine. The question was whether the bar should be removed by dredging, or by extending the training-banks. He advocated both plans; and, while wishing as much training as possible to be done, suggested that if sufficient improvement could not be effected by training alone, dredging might be adopted later on. He thought that where bars were likely to form very rapidly, it was not altogether wise to resort to, or rely wholly upon, dredging. A harbourmaster might one day report that there was a depth over the bar of, say, 16 feet of water, and some vessel might go out after a gale, and find perhaps only 14 feet. He certainly considered it dangerous to rely solely upon dredging, although almost anything could now be done with powerful dredging plant in keeping down bars, especially by suction trailing hopper-dredgers, which received the coarser particles of sand into their hoppers, and allowed the finer held in suspension to flow overboard, and thus by the ebb to be carried harmlessly away far out to sea; but, after all, dredging was expensive and uncertain in its operations, and to be of service must be continued at a rate equal to that of deposit, which, in some cases, was very great indeed; and therefore to train first, and remove by dredging that which could not be displaced by scour, would appear to be the safer and more economical course to pursue. At Irvine the ebb was almost equal to the flood, and the prevalent gales were from the westward. To improve the bar he reported in favour of low training-banks, following practically the sides of the bed of the channel. It was true the bar would shift further out, with the extension of the training-banks; still it was neither difficult nor costly to follow it out to deep water. It would have been unadvisable to have adopted very high training-banks, so they were to have been kept low enough not to be much affected by the waves.

Mr. Kinipple. Another case to which he referred was at Girvan, where there were two short old piers of rubble. The ebb was from the north, and was much stronger than the flood from the south, and the heaviest gales were generally from the westward. The engineer who preceded him had proposed to build a couple of piers parallel with each other in extension of the old works. The bar was immediately in front of the entrance, and could only be removed by dredging. The new south pier, 450 feet long, went straight out; but the north pier, 750 feet long, was laid diagonally, with the result that the alongshore ebb was trained by it, and meeting the river ebb at the entrance, shifted the bar to the south side, leaving ample room for a fair line of entry to the harbour. As a portion of the bar was composed of boulder-clay, it had to be dredged. Since the construction of these piers, about seven years ago, he had not heard anything more about the bar. Another case to which he might refer was Yarmouth. In the year 1030 the entrance to the Yare was 1½ mile to the north of the town of Yarmouth; now it was about 2½ miles south of it. In almost every case where he had been consulted the local authorities had advocated a pier, or extension of a pier, on the side of the entrance from which the shingle or sand travelled, in the belief that by arresting the travel the entrance would be saved from being blocked up. Under any circumstances such works could only be regarded as temporary checks, for as soon as the shingle or sand had been heaped up to the top of the pier, it was either tumbled over into the entrance, or driven round the pier-head, there to block up the direct or fair line of entry to the harbour, and commence anew another spit like that at Yarmouth, which had travelled southward until stopped by a Dutch engineer, Joas Johnson, who, in the year 1560, cut a new channel through the shingle spit, and erected on the opposite side to the travel of the sand the present south pier. The entrance to Poole Harbour afforded another example. Here, all that was necessary for the removal of the bar was to lay down a submerged groyne, or mole, of heavy blocks of concrete, founded on a base of large-sized rubble carried up to, and through, the bar on the opposite side of the entrance-channel to that from which the sand travelled. Again, at New Quay, Cardiganshire, the head of a pier was washed down, and the debris was strewn groyne-fashion at about right-angles with the inside face of the pier. There the heaviest seas worked round the bay, and carried with them a considerable amount of sand. The mound formed by the debris from the ruined head, for its full length, arrested the sand,

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and thus the harbour was in a very short time blocked up; and obviously, to open up the harbour again, it was only necessary to remove the debris, and allow the sand to drift as it did formerly past the base of the old head. Since 1880 he had been engaged in training the channels of the Burry Inlet in South Wales. In August 1883, about a year after the main training-works were commenced, a broad travelling spit, which had worked its way up the estuary for many years from Burry Port, a distance of nearly 4 miles, crossed the entrance to Llanelly Harbour, and travelled ¾ mile beyond towards Carreg-fach; this blocked up the fair line of entry to the harbour to nearly half-tide level. Had the growth of this spit not been arrested, Llanelly, with its thirty thousand inhabitants, and export-tonnage of nearly a quarter of a million, would have been so sanded up as to have ceased to be a port of any consequence. The harbour scour-water at Llanelly, however, during this unsatisfactory state of things kept open a small back or scour-channel along the inside of the spit towards Carreg-fach, then by a curve to the south, and which finally joined the low-water channel at about ½ mile out from the harbour. Here was a close resemblance to the conditions that existed at Yarmouth prior to the erection of the south pier by the Dutch engineer. He hardly knew of a more serious case than that at Llanelly. A spit of about ⅓ mile in width, by about 13 feet in height in places, travelling past the harbour-mouth, with a certainty of blocking it up within a short time. To arrest and remove this spit, of nearly 5 miles in length, extending along the shore from Carreg-fach to Burry Port, was a matter for anxious thought. The local authorities tried, by the use of a necklace of wobblers, and also by balks of timber held by chains, to open a channel through the spit, but without avail, for some of the wobblers were soon buried. The first step he took to relieve the congested state of the harbour entrance, was to block up with slag the scour-channel, although it was then the only course left open for access to the sea. At the time there were several vessels in the harbour, and the risks of blocking up this channel appeared very great; but he felt sure of success, as there were ready and willing hands, who rapidly raised the slag-bank until it was as high, if not higher, than the crest of the spit in front of the harbour. When the sluices were opened, the scour-water slightly raised the pent-up water inside the harbour, until it began to trickle over the crest of the spit, and, by the aid of shovels, a small water-course was opened up, and in a short time the spit of sand was burst through, and thus within a few days a channel of

Mr. Kinipple. nearly 100 yards in width by 500 in length was formed, and the scour-water made its way from the end of the new channel through the sands to the low-water channel, which was then about ½ mile out from the entrance to the harbour. This newly-made channel, to be of use until the main training-bank was completed, had to be kept open by a training-bank of nearly 600 yards in length, which was laid down on the opposite side of the channel to that from which the sand travelled. As the main training-bank was now nearly completed, this bank would be removed. Having opened a new channel through the spit, next came the important question of driving this enormous spit back to sea, or to any other resting-place outside the course of the new sea-channel, and of restoring to Llanelly Harbour and Burry Port the former depths of over 25 feet at high-water of spring-tides. The main training-bank was commenced in 1882 at Salthouse, and had been extended up to Penclawdd and down to Llanelly Harbour to a point at about ½ mile out therefrom. Up to the present time some 20 or 30 million tons of sand had been scoured from the course of the new channel. The main training-bank works had been instrumental in removing the sand-spit for its whole length within a few years, and there was now a good and safe channel, from the entrance to the harbour out to sea, of more than 25 feet at high-water, or double the depth there was in 1883, with about 33 feet over the bar at the mouth of the estuary. These examples of river, bar, and estuary work under his immediate direction would, he thought, suffice to support some of the conclusions at which he had arrived, and to show that very careful consideration should be given to questions relating to any proposed improvements of rivers and estuaries prior to the commencement of dredging, or the laying down of permanent training-banks. He concurred generally with the Author's conclusions as to estuaries having natural deep-water channels; but if *Fig. 1* was intended to illustrate an example of a well-trained estuary, to be followed generally by engineers, then he did not altogether agree with him, for the mouth of the river as shown had a somewhat wandering and uncertain appearance; and if the method there illustrated was closely analyzed, he believed it would be found that the river should have been trained by a right-hand bank only, having an easy curve from the head of the estuary passing near the upper letter D down to the left-hand headland, where its outlet to the sea should have been placed, and where, also, a pier or mole should have been run out, having a slightly concave face, against which the trained ebb-current, on leaving the outer end of the main

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training-bank, should have been made to impinge: this aided by the outside ebb, and heaviest gales striking the outflowing river ebb-current at an angle of about 100°, should keep an entrance so designed open and free from bars. Of course these remarks were based upon the assumption that all the conditions were as he described. To illustrate further what he meant, he would take a like-sided, bell-mouthed estuary, having a rivulet at its head, a straight foreshore line between the two headlands, the strength and duration of the ebb from left to right being somewhat greater than those of the flood from the opposite direction; and the heaviest seas at right-angles to the foreshore, driving directly up the estuary. Under these conditions, he ventured to say that if an inexperienced engineer were called in to open up a new channel or waterway from the rivulet at the head of the estuary out to sea, most likely he would train a channel down the very centre of the estuary directly in opposition to the heaviest gales, using two training-banks, instead of one bank, and gradually increasing the width between them until the sea was reached. On the other hand, an experienced engineer would most probably have trained a channel somewhat diagonally; that was, by commencing at the top left-hand corner with one bank only, and running it across the estuary in the direction of the right-hand headland, where he would construct a pier, as before described, against which the outflowing ebb would impinge. The inexperienced engineer, however, by his action would first create a bar outside, then perhaps one or two bars inside, and ultimately, if dredging were not resorted to, the bar, being worked up by the river and sea forces, would, aided by the constant supply of debris sent down by the upland water, ultimately lose its character as a bar and become an ordinary delta; and so the debris deposited at the mouths of the minor channels along the margins of the delta would by the heavy on-shore seas, striking the sides of the delta, be deflected and caused to travel towards each headland. At this stage the mouth of the main channel would gradually close up; minor channels would be created, and ultimately there would be formed two tolerably well-defined outfalls, by the river having bifurcated some distance up from the original line of foreshore, each being driven in the direction of the nearest headland, and to prevent which most likely he would repeat the act of the engineer who ran out a pier on the travel side of the channel and diverted the mouth of the River Yare, 4 miles to the southward of its original position. Thus one engineer would so place an entrance to a river that a bar, delta and spit would be formed; while another engineer would so place

Mr. Kinipple. it as to free itself from such obstructions. Generally, to avoid bars on the west coast of England, the mouth of a trained river should be on the northern side of an estuary, and trained in a north-west to northerly direction against a pier or promontory. That was, the outfall should be on the opposite side to that from which the sand or shingle travelled, and from which the prevalent gales came. On the east coast an outfall should be on the southern side of an estuary, and trained in a south-easterly to southerly direction. The outfalls of the rivers in the Dee, Mersey, and Ribble estuaries could be easily, economically, and successfully dealt with. The reclamation of saltings, which were perhaps only covered a few times .each spring-tide, in his judgment was bad in practice, no matter where they were situated; for reclamation simply induced further accretion, and so the process went on until the top water of high-water of spring-tides was ultimately shut out, and the surfaces of the higher portions of the bed estuary were robbed of the beneficial washing down of the film of sediment which usually took place in estuaries as the tides fell off towards the neaps. From the small models he had used, he was sure tolerably trustworthy results could be obtained, and especially by one 6 feet in diameter, having sides 3 or 4 inches high, a glass bottom, radial arms 3 feet across, driven by clock-work from a centre-pin, at a speed sufficient to move fine silver sand, and capable of being worked from the right or left, to represent ebb-tide and flood-tide; also a wave-maker, likewise driven by clock-work, and mounted in such a manner that any angle could be obtained. And if small models of piers, groynes, training-banks, mouths of rivers, narrows, estuaries, &c., were made of cast-tin and placed on the glass in proper relative positions to the currents and waves, and fine sand was dropped into the water, the gradual formation of banks, bars, the deepening at concave faces, and of narrows, arresting of the travel of sand by groynes, formation of spits, &c., could be pictorially displayed, and watched with interest, especially if observed in a dark room, with a light beneath the model.

Mr. Hayter. Mr. HARRISON HAYTER, Vice President, with respect to the forces in operation in the formation of a bar in a tidal sea, took as an illustration the case of what might be regarded practically as the creation of a new river with an outfall into the sea. He alluded to the Amsterdam Ship Canal,[1] which entered the North Sea on the Dutch coast, the mouth being protected by two sea-piers or breakwaters, each about 1 mile long. The coast and the

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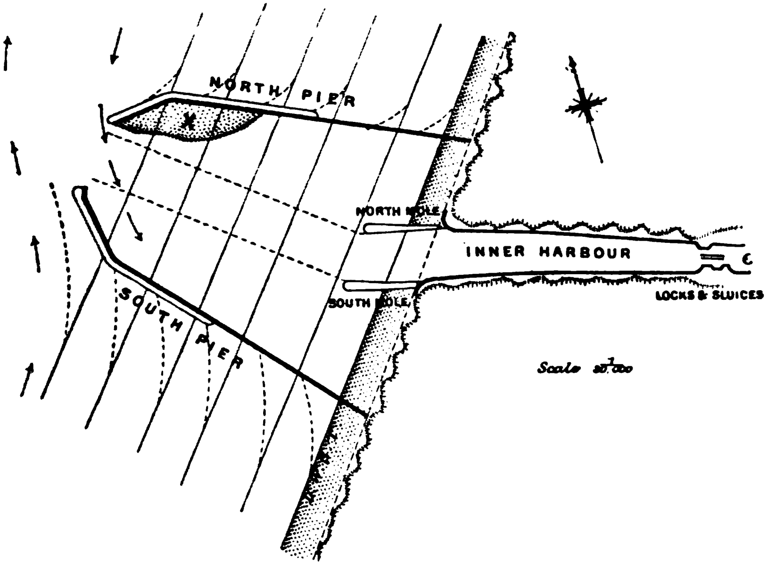
[1] Minutes of Proceedings, Inst. C.E., vol. lxii. p. 1.

Mr. Hayter. foreshore were sandy, not only at the site of the piers, but for miles northward and southward. In 1880, the date of his Paper on this work, the sea-piers had not been completed sufficiently long to enable conclusions to be drawn as to the effect they would produce on the surrounding regime. Now, however, what had taken place was illustrated by *Fig. 2.* The continuous contour lines showed their general direction before the piers were begun. The coast-line being regular, these contour lines were more or less regular also, and parallel to the coast. The interposition of the piers broke the continuity of the contour lines, and it was not very material whether this was done by piers or by land or tidal waters, as the result would be generally the same. The dotted contour lines showed the manner in which sand was accumulating behind the piers by the winds and currents, the accumulation being greater behind the south pier than behind the north, because in the former case the operating forces were the stronger. Another disturbance in progress was due to the diversion of the sea currents. Before the piers were begun the direction of the current was generally parallel to the coast, and the velocity from 2 knots to 2½ knots an hour. Now, however, the current was deflected, as shown by the arrows, and

Fig. 2.



Mr. Hayter. the velocity at the end of the piers increased to from 3 to 4 knots an hour, dependent on the direction and force of the wind, and there was a resulting eddying current which entered the harbour setting over towards the south pier at and near the end, and creating a sandbank under the lee of the north pier at X. If these accumulations outside and inside were allowed to go on uninterruptedly (and the case would be the same everywhere under similar conditions), the piers would in the course of years be high and dry. How long this would take in the absence of preventive measures it was of course impossible to say. These measures consisted of scour and dredging. Scour was obtained by means of water from the canal as well as from the tide. About ¾ mile inland from the coast there were locks and large sluices, and there was almost always water to run off from the canal, and generally a large surplus to be pumped by powerful pumping-machinery, discharging into the Zuider Zee. The land water sent through the sluices, in conjunction with the tidal water which filled the area between the piers and the widened channel or inner harbour between the coast and the sluices, scoured the entrance to the canal to some extent, directed as these waters were by low interior moles. The rise of the tide, however, was only from 7 to 10 feet, and the scour had to be supplemented largely by dredging. All engineering works needed maintenance, and the annual cost of the dredging was considerable, although it could not be regarded as excessive when compared with the value of the canal, to the city of Amsterdam in particular and to Holland in general, and was not more than might be expected, considering the conditions. He referred to this case because it was an apt and suggestive illustration. A new river, as it were, had been called into existence. A bar was in process of formation by the winds and currents, and systematic observations showed the accumulations and successive encroachments. The study was an instructive one, and illustrated exactly the way most bars were formed in tidal seas. He could only say that, whatever theories there might be as to the formation of bars, the state of things he had described was doubtless due to the prevalent winds and resulting waves, and to the littoral currents in a tidal sea, the injurious influences which would arise therefrom being checked by counteracting measures—that was to say, by scour and dredging. If the sea were tideless and without currents, then the formation of a bar must, as a rule, be sought for by matter in suspension brought down by a river being deposited where the velocity of the river water was checked by mingling with the sea.

Mr. Shelford.

Mr. W. **Shelford** said that the Author had undertaken a difficult task, and he thought it was not too much to say that those who understood the subject best would thoroughly appreciate the ability which he had shown and the pains he had taken in executing it. He might be permitted in the first place to refer to some remarks of Mr. Kinipple with reference to the Clyde, a river in which he had taken some interest as long ago as 1873, when a Paper was read respecting it by the engineer of the river, and Mr. Shelford took part in the discussion.[1] With respect to Garvel Point, it was stated that as fast as the point was cut off, the sand accumulated upon the other side of the channel, and no improvement was effected. Whether or not such a silting would occur in a broad estuary, having separate flood channels and ebb channels, was a matter of importance because of its general application. Mr. Shelford had received a communication from Mr. David Alan Stevenson, who represented the firm of Messrs. Stevenson, in which he stated, "The line of the river channel was fixed by Messrs. Stevenson, representing the Clyde Lighthouses Trust, and Sir John Hawkshaw, representing the Greenock Harbour Trust, and if that particular part of the river channel line coincided with what Mr. Kinipple recommended in 1868, he was not aware of it. Garvel Point was cut off under the directions of Messrs. Stevenson, and 240 feet was taken off, the object being the straightening of the channel, and bringing the scour of the flood and ebb-tides closer to the Greenock Harbour. Up to this time there is no appearance of any appreciable amount of silting having taken place in any part of the new channel. The works are nearly completed, and have proved entirely successful, and ship-masters and owners are quite satisfied with the results that have been attained. The depths of 18 feet and 23 feet, at low-water, provided by the Act, have been procured, and the channel widened and straightened. The dredging operations at Greenock during ten years have extended over 4 miles of channel, much of which was in hard boulder-clay. The channel opposite Greenock has now a uniform depth of 23 feet at low-water, in place of a ruling depth of about 20 feet." The point in which he was particularly interested, namely, whether one of the channels in an estuary, when excavated on one side, would necessarily fill up on the other, was therefore entirely in dispute and as unsettled as ever, Mr. Kinipple having maintained that it was so, and Mr. Stevenson saying that it was just the other way.

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[1] Minutes of Proceedings Inst. C.E., vol. xxxvi. p. 188.

Mr. Shelford. More than half of the Paper was taken up with an investigation into the causes of bars, and properly so, because it was obviously useless to attempt to remedy a bar unless the exact cause of it was known. The Author went as far back as two centuries, and referred to what the Abbot Castelli then said about bars in a tideless sea: "The Abbot Castelli expressed the opinion that the obstruction to the entrance to the ports in the Mediterranean proceeded from the violence of the sea, which threw up a body of sand of the shape of a half-moon at the place where the river fell into the sea." It might be well for a moment to consider a bar in its most elementary form. When a stream discharging into a basin of still water, and carrying in suspension a large quantity of detritus reached the coast line, it commenced to deposit sediment, and the deposit took the shape of a half-moon or horse-shoe. Owing to the velocity at the sides of the stream being less than the velocity at the centre, the stream first deposited upon each side, while the centre particles were carried further forward, and in that way the horse-shoe or half-moon shape was obtained. But not only had the centre of the stream a greater velocity, but a greater volume, and therefore carried a larger quantity of silt, depositing much more in front than upon the sides, so that a heap or shoal was formed in front; and, supposing the water to be still and everything accurately balanced, there would be a stream discharging on the one side and on the other. He thought that in that way rivers discharging into tideless seas, like the Nile, the Danube, the Rhone, and many others, might, apart from other causes, have formed for themselves several mouths. But if there was the slightest disturbing cause outside, the balance was at once altered, and there was a discharge from one side only. With a prevailing wind from one direction and the sea breaking upon the coast, one side of the bar would be lower than the other, and there would then be only one channel of discharge. In proof of that he would refer to a chart of the Tiber mouth made from the Admiralty official chart published in Italy, which was produced at the Institution in connection with a Paper which he read in 1885 upon rivers discharging into tideless seas.[1] The chart showed a horse-shoe bar with a shoal on its centre. The prevailing wind was from the south-west, and it broke upon the bar, making the greatest depth 6 feet 6 inches on that side, while on the other the depth was 2 feet 6 inches; and the Tiber had only one natural mouth, the smaller one being artificial. Accurate records had been

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxii. Plate 1.

Mr. Shelford.

kept for centuries, and it appeared that the accumulations of the delta on one side of the river had been 50 per cent. more than upon the other side during the last three hundred years. There was therefore an outside cause in the case of the Tiber which had upset the ordinary action of its most simple and elementary bar. The conclusion he drew was that any river discharging detritus into a tideless sea would naturally have a horse-shoe bar, and the fact of a horse-shoe bar existing proved that the down-stream was the cause of it, and that it was not caused, though it might be modified, by the sea. In the case of Liverpool there was also a horse-shoe bar, and from its shape no one could suppose that it had been formed otherwise than by the ebb-tide, and yet, having a ridge of 5 miles in length, and being virtually an enormous bank, it was impossible to conceive that it was supplied with material for its maintenance from the small water-sheds of the two rivers, the Mersey and the Weaver; and there must therefore be some other cause. He had pointed out in connection with the Paper by Mr. Lyster on "Recent Dock Extensions at Liverpool" that the flood-tide and the prevailing wind drove the sands from the west into the main channel of the Mersey. If that were so the channel must of necessity fill up unless the sand was removed. But it was not filled up, and therefore the ebb-tide, which was very powerful in the channel coming from Liverpool, must roll the sand along the bottom, and deposit it in water of low velocity, thus forming the bar. That was further proof that the bar was caused, or rather maintained, by the ebb-tide. It was not a new idea. Admiral Spratt, then Acting Conservator of the Mersey, some years ago prepared a map and report, in which he showed from the analogy of another place, which he had carefully studied, that there was what he called a circulation of sand always going on, the sand being constantly thrown up into the channel, and being carried down again, and deposited on the bar. He would suggest to the Author that this was also the probable cause of the Boston bar. He knew the Wash and Boston, but not in sufficient detail to be prepared to say that it was the cause, and he suggested that the Author, who had charge of a great part of that estuary, should consider that point. The main set of the tides and winds, especially the winds, was across from east to west, so that when the waves broke on the Long Sand they would drive it into the Boston Deeps, which would therefore be filled up were it not for the action of which he had spoken—the ebb-tide rolling the sand back again to still water where it formed the bar.

He wished now to call attention to his model of the River

Mr. Shelford. Humber, made many years ago, which illustrated the action of the tides within that estuary. There was no bar at the mouth of the Humber. There was deep water instead at low-water from 72 to 108 feet between the mouth and the open sea. The Humber contained an enormous quantity of alluvial matter, finely comminuted, which rested nowhere but in still water. There was no material carried down by the river of sufficient size to stand the action of the sea, consequently what was discharged from the Humber was found in the shape of mud in places where there was slack water only, especially off Cleethorpes and Saltfeet, where there was an area of slack water which escaped both the ebb-current from the Humber and the ebb-current from the Wash going northwards. The reason why the Humber was so very muddy was probably that there were great embayments upon it. The formation of the mouth was remarkable, there being a natural groyne (Spurn Point) formed by the action of the waves. Inside that groyne there were thousands of acres of land where mud was deposited by the ebb-tide, and returned by the succeeding flood. He thought the reason why the Humber was so muddy was that the mud did not escape so freely as from trumpet-mouthed rivers, but the mud did not tend to form a bar. On the other hand there was an action going on outside which was very important. For 30 miles north of Spurn Point the coast was diluvial clay, which contained shingle, and this was carried forward by prevailing winds and the flood-tide to Spurn Point (where the President had trapped a great quantity of it and so had preserved the Point). That shingle, supposing it to be strong enough to overcome the tide, would close the river, and had already diverted it southward. On the east coast almost all the rivers were diverted by a similar travel of shingle southward. The Yare, for example, had been diverted for miles at Yarmouth, and so with other smaller rivers, and in some cases there were bars. Why there was no bar in the Humber was a very interesting question. He could only account for it in this way; that the ebb-tide was sufficiently strong to maintain a deep channel for about 8 or 10 miles beyond Spurn Point where deep water was reached, and a strong littoral ebb-current was running northward which dispersed the detritus.

Those were one or two examples of rivers, with and without bars, that had come under his own professional observation. It was dangerous to generalize, and he would rather not do so; but he should like to say that he entirely agreed with one of the conclusions at which the Author had arrived, namely, that the causes which operated in maintaining the existence of bars in tidal estuaries came from the sea and were not due to the inland water. But he would add that that did not apply to bars at the mouths of rivers flowing into tideless seas. Mr. Shelford.

Captain W. J. L. WHARTON, R.N., said it was with diffidence that he rose to make any remarks upon a professional subject before a professional society; but he might be permitted to state the view of a sailor who had always taken interest in such matters, and had seen a good many bars. He had listened with great pleasure to the Paper, as the Author's opinions agreed entirely with those that he himself had formed. He was also glad to find his old fellow-officer, Captain Calver, quoted as an authority upon the subject. Captain Calver had written a very able book nearly forty years ago, and had had the satisfaction of living to see many of his views therein expressed, especially in regard to the treatment of bars, confirmed. He had made many reports to the Admiralty, and the correctness of his views had been thoroughly proved. Captain Calver attributed the formation of bars in most instances to what he called the stroke of the sea, and he understood the Author to agree with that view, in which he also concurred. He was not, of course, prepared to say that a bar was caused by one force alone; like other things in nature it was the result of a combination of several forces; but he was convinced that the powerful factor in the formation of such bars as the Author had referred to was the sea. He understood the stroke of the sea to be a violent forward movement of a considerable body of water, whether caused by a breaking sea, or by the horizontal motion into which a wave motion was transformed in shallow water, meeting a considerable outflow of river or tidal water more or less at one spot. He was speaking of a bar as defined in the Paper namely, a more or less narrow ridge, with deep water on both sides of it. To his mind an estuary like the Thames went very far towards proving this. The Author had stated that an estuary gradually widening and deepening was one in which no bar was formed; but he had not gone further than that, and given the reason. In the case of the Thames, if there was a bar, it would probably be at Southend, where the river ended; but the mouth of the Thames was encumbered with many sands, and the sea could not get in there. There was not sufficient sea to move the sand at one particular point; and its force was distributed. There might be bars again at the entrance of the channels between the great sands which were a prolongation of the river, as the Black Deep, but there the estuaries gradually deepened to 15 or 16 Captain Wharton.

Captain Wharton. fathoms. The sea was not very heavy; it had not what sailors called a fetch, a deep undulation; there was not sufficient sea to move the sand and push it forward in opposition to the current. It was different in the case of the Tay. The estuary of that river was not exactly the same formation as the Thames; but the sand had formed, instead of a number of individual sands with deep channels between them, one large sand, crossing the entrance, so that the river was practically prolonged until it met the sea, and the consequence was there was a bar there, the sea being sufficiently shallow. At present, however, he believed it was better than it had been for many years. The Author had used an expression, which he did not quite follow, about a shallow sea aiding the formation of bars. If by that was meant that the estuary of the sea immediately outside where the bar was formed must be shallow, he agreed with him; but if he meant that the sea outside should be shallow also, he failed to follow the argument. It appeared to him that there were many cases where there was a deep sea outside, and consequently a very heavy fetch, beating on a shallow coast, and there would be a bar, just as in the case of the Zambesi, where there was a heavy sea and comparatively deep water outside; indeed, there were no worse bars anywhere than in the Zambesi. There was another little point to which he must demur, namely, that a bar, such as the Tyne formerly had, was no impediment to navigation because the river was shallow inside it. That was scarcely correct; because it was a different thing to cross a bar and to force a way up a shallow river; one thing could be done, but not the other on account of the sea on the bar. He should be glad to know whether the theory advanced as to the bars of the Danube and Mississippi met the Author's approval. He thought they were both unsatisfactory; in both cases the sea had a very large part to play. There was a continual easterly wind at the mouth of the Danube, and he imagined that that must have a great deal to do with the formation of the bar. Supposing there were no sea, the stream running out into a tideless and smooth sheet of water, he could not see that a bar would be formed of the kind mentioned. There would be a great conflict; but the force of the river running into the still water would set up a current which would be carried out a great distance, as was well known in the mouths of great rivers; and the water could hardly be called still. Of course it did not require water to be perfectly motionless to deposit material in suspension; but it needed a very considerable diminution of its velocity, and he could not think that deposition in one spot would occur unless there was some opposing force, which he believed to be the stroke of the sea. Captain Wharton.

Mr. Stevenson. Mr. J. C. STEVENSON, M.P., said he could only give his own impressions from an entirely non-professional point of view of what the situation was on the Tyne before any improvement took place. Having lived there during the whole period from the commencement of the improvements, and knowing what the state of matters had been, his description would be this, that the bar was not a piling or heaping up of sand beyond the natural level, but it was very much the depth of the ocean, along each particular contour line which would have existed if the river had not been there. The contour lines on the Admiralty charts, previous to any works being undertaken in the way of piers or dredging, were scarcely at all thrown out opposite the Tyne entrance, as they ran north and south. The Author had stated that the Tyne was a case where the bar did not affect the navigation. He understood his meaning to be that it did not diminish the depth of water at the place which would have existed if the river had not been there at all. The promontory on which Tynemouth Castle stood, which acted as a natural pier, controlling the direction of the ebb-tide before it joined the sea, no doubt caused a deepening along the line of the promontory, giving deeper water inside what was called the bar than there was at the bar itself. In the same way the contraction of the river in Shields Harbour gave the deep water in that harbour, which formed an anchorage along the concave sides before the recent improvements were adopted. He considered the improvement in the Tyne to be mainly cutting away the sands by dredging, and then, by means of piers running out into 30 feet at low-water, protecting the dredged part so that the waves at that depth had no action at the bottom. It was different where the piers ran across shallow sands, where the channel was apt to be levelled up by the action of the sea. There, the piers protected the bottom from being disturbed, so that the bar so-called having been once dredged away did not re-form finally. It did re-form several times, through the sands which were enclosed by the piers, leaving many acres dry at low-water, being scoured into the channel by the action of the waves. The sands were now scoured away by the waves to what might be their natural equilibrium, having been dragged down into the channel from either side of the large area within the piers. The sands to the south were washed away into the dredged channel, and had to be picked up again. Those sands had been very much diminished in level, and were not so high at low-water as they used to be.

Mr. Stevenson. He remembered a prediction made by an eminent Admiral who was present at a meeting of the British Association in Newcastle, just after the improvements were commenced and the piers designed; the prediction was to the effect that there would be a silting up inside of the piers, and he traced with his pointer the line at which he predicted the silting would take place. But the opposite result followed, the heavy sea there having washed the sands away. He thought, therefore, that the great improvements in the Tyne were due mainly to the extensive dredging which had been carried on, not only at the entrance, and up to Shields Harbour, but to the head of the navigation. With regard to the action of the waves, he could not speak with any confidence; he would only say that the action of the waves at that point of the coast was very severe. There was an unlimited fetch from the North Pole down to Tynemouth Castle, and comparisons could not be fairly drawn between the action of the waves on a coast situated like that, and the action of waves on a shallow coast like the Dutch coast or that of the English Channel.

Mr. Redman. Mr. J. B. Redman considered the Institution was indebted to the Author for bringing forward a subject of much interest to large numbers of the profession, and which must be of the greatest importance to an insular and commercial people like the English. The opinions held in reference to the formation of bars had been as divergent and opposite as was the natural physiography of tidal estuaries and outfalls. A galaxy of eminent names might be quoted of persons who had written largely on the subject of the formation of bars—De la Bêche, Hutton, Playfair, Rennel, and many others. The effect produced by reading their works was a belief that the cause of harbour bars came from inland. He thought that experience would endorse one of the conclusions of the Author, that the causes of bars at the entrance of tidal harbours, at least, were oceanic or marine. In pursuing the subject, engineers were apt to imagine, innocently enough, that their views were more original than they really were, forgetting, ignoring, or not being aware of what many pioneers had essayed in the same direction. About half a century ago a very elaborate report was written and published by Mr. W. B. Prichard on Shoreham Harbour, and it was in the Library of the Institution. Mr. Prichard was in antagonism with Mr. Chapman, one of the leading hydraulic engineers of that period. A few years afterwards he published a work, known as "Prichard on Bar Harbours," A.D. 1844. He had not seen it for many years; but, judging from the tenor of the report on Shoreham Harbour, the writer would probably have

Mr. Redman.

endorsed the Author's conclusions as to the origin of those formations. About a decade after the publication of the book Mr. Redman contributed a Paper to the Institution on the South Coast of England,[1] and eight or ten years subsequently another Paper on the East Coast of England.[2] He would not go over well-trodden ground, but would simply remark that the tidal outfalls along the whole stretch of coast, from Portland to the Wash, showed indubitably that, of the forces producing the bars, the prime motors were the winds and their attendant waves. All the harbour outlets on the southern coast trended up channel to the eastward, owing to the prevailing south-westerly winds; and all the outfalls on the eastern coast were deflected southward, being open more especially to north-eastern gales. Without going much into detail, he would point to four examples on that stretch of coast directly illustrating that position—Yarmouth and Harwich on the eastern coast, and Folkestone and Newhaven on the southern. The town of Yarmouth and its parish church, St. Nicholas (said to be the largest in England), stood upon an ocean bar; and in the graveyard it was necessary to timber the graves in burying the defunct inhabitants. The harbour had had something like six outfalls, and it was not until the Elizabethan period that the outfall became permanently directed at the Gorleston end by Dutch engineers. In more modern times the attempt had been made to maintain that outlet. The endeavour of the effluent waters had always been to creep down to the south, and on one occasion the water did effect an outlet as low down as Corton. The President was perhaps better acquainted than any member present with the modern efforts to maintain the channel, having been professionally connected with the harbour for some years. Harwich told the same tale. At one time it almost shared the same fate as Yarmouth during the Edwardian period, being almost filled up by the travelling shingle across the mouth, so much so that the high light and low light that had been in use for many years were disestablished, and a new high light erected southward of Harwich, and a light on the point. The low stone breakwater or groyne running out from Beacon Cliff was erected forty years ago, pointing towards Landguard Point. Its object was to confine the effluent waters upon the ebb, and direct them towards Landguard Point, with a view of checking its advance. The work had no influence on the Point; it still went forward to the

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[1] Minutes of Proceedings Inst. C.E., vol. xi. p. 162.

[2] *Ibid.*, vol. xxiii. p. 186.

Mr. Redman. southward and the westward, and appearances seemed to indicate that the harbour would eventually be choked up. Subsequently a timber groyne was erected on the Felixstowe side to the northward by Mr. Brough, and the effect of it had been to prevent the travel of the shingle to the southward, arresting it before arriving at Beacon Cliff; and that, coupled with dredging, had maintained the channel. The harbour in the time of Henry VIII. was a Royal dockyard; it was never accounted of any great importance even at that period, and had now only 13 or 14 feet at low-water. Those, he thought, were samples that endorsed the position that the origin of the formations in question was oceanic. Five years ago a committee was appointed by the British Association to report upon the erosion of the shores of England and Wales, and whether it was checked or hastened or influenced in any way by artificial works. The Admiralty Hydrographer, Captain Wharton, was a member of that committee, and for the first two years Mr. Redman was a working member. Recently, however, the existence of the committee had been rather mythical—they now never met, and the work had been mainly done by the acting secretary, Mr. W. Topley. Two or three reports had been issued and a large amount of information collected, and the results of the inquiries made had been to endorse the position that the origin of bars in tidal harbours and estuaries was oceanic. It would be a bold attempt to lay down any definite plan for dealing with bars along the shores; but it was clear that where there was a large fetch of sea into a tidal river, parallel piers conducting the effluent waters presented many arguments in their favour. Where, on the other hand, there was no back-water, piers like those of the Liffey, the Tees and the Tyne, the wide part next the shore converging towards the outlet appeared to be the form most likely to deepen a channel, assuming that the piers went into deep water free from deposit. But there were a large number of harbours, such as those of which the Author had special knowledge in the estuaries of the Wash and other localities of that description, where the trade would hardly warrant such an outlay. Where the foreshores were of a different character, composed of sand and ooze, guiding-banks, which would allow the tidal water to flow from the foreshore into the channel, appeared to be the most desirable mode of treatment. In regard to training-banks a large amount of work had been carried on by American engineers, respecting which there was a very great difference of opinion. He would refer to a paper published two years ago by Professor L. M. Haupt, an American engineer, on "Harbor Entrances," and the allegation made by him and other critics was, that, with many of those training-works, there was an enormous amount of accumulation on the windward side, and a corresponding gulling out or deepening on the lee side, with shoals beyond their terminals where their influence ceased, and in some of the roadsteads where those training-works had been executed, the harbours generally carried less water than they did before their inception. Mr. Redman.

Mr. A. Giles, M.P., Vice President, agreed with the Author generally as to the causes of bars. It had been stated in the Paper that they were not so often caused by the fresh water of rivers as they were by the action of the sea; and he had an instance in his mind where one side of the bar was composed of silt brought down by the river, and the other side was composed of sand brought up from the sea. But one thing seemed to be difficult to understand. Why was it that the seaward slopes of the bars of the Mersey and the Ribble and the landward slope were steeper than the natural slope of the soil? He should be glad if the Author would state whether he knew any cause to which that could be attributed. He quite agreed that a funnel-shaped estuary of a river like that of the Severn and the Thames was more likely to be free from bars than other rivers. He had given very good instances showing that it was not always detrimental to the bar of a tidal river to cut off the sinuosities and bays; but he agreed with the general principle that the more water admitted into a tidal river, and the more water let out, the better chance there was for keeping the channel open. At the same time he admitted that the water coming over sandbanks at a level far above low-water had little effect in keeping the channel clear. There were many instances of regulated rivers. He might instance the Tyne, which he remembered when there was not more than 6 or 7 feet depth of water over the bar. But it had now been increased to a depth available for large steamers, principally by regulating and dredging. The Tees was another example of the same kind. The Author and he had also been engaged in the investigation of another river—the Ribble—where they hoped the same result would follow. But where the tide rose, as in the Ribble and the Mersey, to something like 30 feet, vessels were rather independent of bars, because if they could have 6 or 9 feet, as in the Mersey, over the bar at low-water with 30 feet of tide, they were pretty safe to get into the dock entrances. Another suggestion of the Author's was, that no good could be done by constructing piers to regulate or improve bars, unless they were carried into deep water. There was pretty good evidence of that in the case of Mr. Giles.

Mr. Giles. Yarmouth and Lowestoft. There the set of the shingle had driven the mouth of the river Yare 2 or 3 miles south of the direct line in which it would have naturally come; the discharge at Lowestoft had not gone to that extent, because a pier had been constructed to stop the shingle, and allow the water to go out in its proper course; but the water at the back of that pier was gradually shoaling, and the pier would have to be extended into deep water before any permanent good could be done. He had an instance before him in his own practice, in which he thought it desirable to widen a river. It was found after long experience that there was just sufficient water to keep the old river open without deposit; but when he widened the river 50 feet, and made a quay for the purpose of benefiting the navigation without obstructing the other part of the river, he had found that the consequence of the widening was, that there was a deposit alongside the quay, which had never occurred before in the river. That, he thought, was a proof that a river would to a certain width maintain its regular depth; but if an attempt were made to widen it without increasing the volume of water going through the channel no good would be done.

Mr. Hurtzig. Mr. A. C. Hurtzig observed that although a good deal had been said on the subject, he might be permitted to make a few remarks, having been for eight or ten years engaged in the construction of large works in the Humber estuary, and having studied tidal questions to a greater or less extent. He thought the abstract question whether bars were due to causes which arose in the sea, or to causes arising in the river, was not of serious import to engineers, provided they were able to determine the causes which tended to their continuance, and were able to design works which would counteract those causes. The Paper had given a good deal of food for reflection on the question of bars, but he would confine his remarks within narrow limits, which would have a greater bearing on the Mersey, perhaps, than on other bars. The Author stated that a sandy bar, in a tidal estuary, owed its shape to causes arising from the meeting of the ebb and the flood currents at a point where their effect was at a maximum. He could not understand that statement. In a tidal estuary, such as the Mersey, there was no particular point where the ebb and the flood current met any more than at other points, every point from end to end of the tidal compartment was successively a point of meeting of the flood-tides and ebb-tides. The only places that he knew of where there was really such a meeting of tides and conflicting currents were such as that described by Admiral Beechey, in the Irish Sea, where two main branches of the ocean tide came round the north and the south coasts, meeting between the Isle of Man and the coast of Ireland. There was a place where there was absolutely slack water, and the bottom of the sea was covered with soft mud, slack water being due to the conflicting effect of the two flood currents; yet close by, in the narrow pass between the Irish Coast and the Mull of Cantire, there was a channel 140 fathoms deep, scoured out by the flood-tides and the ebb-tides passing through at a high velocity. Taking the case of the bar at the Mersey; the very existence of a bar indicated that there was a permanency of slack water, not temporary slack water at the turn of the tide. It was well known that a tidal current of 3 feet per second, equivalent to 2 miles an hour, would move shingle; and therefore a sandy bar like that of the Mersey, with 9 feet of water upon it, could not exist unless there was permanent slack water. Such slack water could only be due, he thought, to two causes, either to a continuous undercurrent which was always opposing both the flood-tide and the ebb-tide throughout its normal progress in and out of the estuary (which was hardly conceivable), or to the dispersal of the water into larger and larger channels, which dispersal left the water passing over the bar to pass in and out at a slow and almost constant rate. He had taken the Admiralty Chart of the Mersey to see to what extent that view could be borne out by facts, and he had taken some sections of the various approach-channels to the Mersey. He found that the gross area of the low-water channels passing through the banks into the Mersey estuary was about 150,000 square feet, of which about one-half, or 80,000 feet, received water which passed over the bar. An hour and a half after low-water, when the tide had risen 6 feet, the area of the channels which fed the Mersey was about 300,000 square feet, and the water which passed over the bar was only $\frac{1}{7}$ of the total instead of $\frac{1}{2}$, as in the previous case. That showed that there was a dispersal of the water, and that the flood-tide which fed the estuary did not necessarily pass over the bar at an increasing velocity; and the rate of 4 or 5 miles an hour in the inner estuary could not, over the bar, be more than such as would leave a sandy bed unmoved. If that view were correct, he thought that the works of the engineer to counteract that force, which tended to the continuance of a bar, should be such as to increase the velocity over the bar, by closing the subsidiary channels and preventing the dispersal of the water to which he had referred; and he also thought that the various improvements carried out on the bars of the Tyne and the Tees, and on other

Mr. Hurtzig.

Mr. Hurtzig. sandy foreshores, were due largely to the appreciation of that fact.

Mr. Wheeler. Mr. W. H. **Wheeler**, in reply to the discussion, said that the point raised by Mr. Hurtzig was a mere difference of words. He had laid down clearly enough that the way to remove bars was by concentrating the ebb current and strengthening its force by training-works or otherwise, and that appeared to him the conclusion that Mr. Hurtzig had arrived at. Mr. Hurtzig objected to the statement that the actual shape of a bar was due to the contending forces of the ebb and the flood currents when they were at their maximum. If it was not due to that he was at a loss to account for the shape of the bar. Mr. Giles had also asked why the bar should be of the peculiar shape referred to. Mr. Wheeler had studied the subject and had tried to find out a cause for this. In order to watch the action of water on sand, he had a model constructed in which he let a stream of water continuously run down carrying sand with it, and he had also closely observed the models of the Mersey which Professor Osborne Reynolds had made some time ago, and watched the action of the water. The only conclusion he could arrive at was that when the two contending forces, the ebb and the flood, met, as in the case of a collision of railway-carriages, they telescoped. There was a continual rotary action of the water working upwards which drove the sands up and held them in the peculiar position which they had in a bar. He could not see any other way of accounting for it. When sand was being moved along a channel, it was not carried by the water in a thin film spread over the bottom, but assumed the form of a series of long slopes on the upper side, or that from which the current was coming, with steep faces on the lower side, something in the form shown in *Fig. 3.* Over this face, or tip, the particles of sand were rolled, the crest gradually advancing forward. In a tidal channel, where the current was continually reversed, the position of the faces varied with the direction of the tide. At the junction of the channel of an estuary with the sea, where the conflict between the ebb-tide and flood-tide took place over the sand being rolled into the channel by the littoral current and the bar was maintained, a somewhat similar action went on. The particles of water of the flood-tide or ebb-tide on coming in contact with the ridge of sand lying across the channel were deflected upwards, as shown by *Fig. 4*, and carried the moving sand over the top of the ridge. A rotary or screwing motion was also set up, which whirled the sand round the bottom of the hollow at the foot of the ridge, continually scouring it deeper, *Fig. 5.* The particles of water which passed over the ridge and down the other side in like manner whirled round the sand at the inner foot. It was owing to this rotary action that the ridge and also the depression which was always found on either side of a bar were maintained. It was also due to this action that the pools in rivers and the deeps, such as the Sloyne in the Mersey, or Lune Deeps in the Irish Sea, were kept from being filled up by detritus. Captain Wharton had also asked him **Mr. Wheeler.**

Fig. 3.

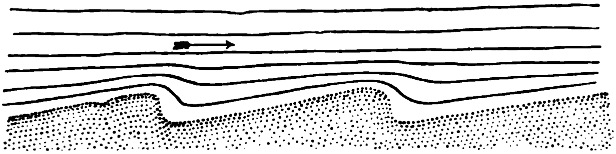


Fig. 4.

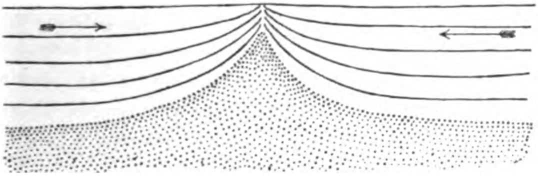
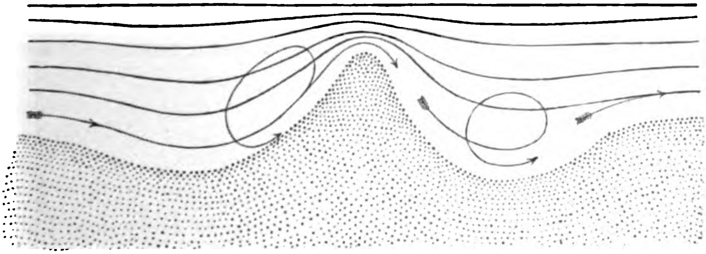


Fig. 5.



a question with regard to such rivers as the Danube. The distinction he had drawn in the Paper was that, in a river like the Danube, the material of which the bar was composed came from the land, and not from the sea; but in a tidal river the matter came from the sea and not from the land. The material of which a tidal bar was composed was pure sand and not diluvial matter. Mr. Shelford had stated that he thought the cause of the bar at Boston Deeps was the tide setting over the Long Sand and washing

Mr. Wheeler. the sand into the channel which was carried by the ebb. That, no doubt, was correct. The tide did set over the Long Sand, and in setting over it carried some sand into the channel. If this sand was not fed from somewhere it would have long since disappeared, and the feeding material came from the sea. Mr. Vernon-Harcourt's criticisms, he thought, had rather confirmed what he had stated. He seemed to think that sufficient importance had not been given to the value of fresh water, and the case of the Ouse was instanced, where deposit had taken place in the summer, and it was removed in the winter. That was a valuable illustration, confirming what he had stated in the Paper, and showed the service which fresh water rendered in maintaining a tidal river. Mr. Vernon-Harcourt had also challenged the statement as to the effect of applying training-works in the upper estuary of the Mersey, and the remark made in the Paper that the bar of the Mersey deteriorated with the freshets that took place in the upper Mersey. The estuary of the upper Mersey consisted of a large quantity of pure sand, similar material to that of which the bar was composed; and it was a singular fact that the bar of the Mersey deteriorated whenever there had been heavy freshets down the Irwell, or the Mersey. He had prepared a Table commencing with 1864, showing the depth of water on the bar, and the rainfall.

Year.	—	Depth on Bar.		Rainfall.	—
		Ft.	In.	Inches.	
1864	Victoria Channel	15	0	30·64	A great fret began about 1860 and continued to 1869.
1865	Do.	13	0	28·39	
1866	Do.	12	0	43·17	Great flood in Irwell.
1867	Queen's Channel	10	0	34·58	
1868	Do.	10	0	32·23	
1869	Do.	9	0	35·45	Great fret off Stanlow Point; 5,800,000 cubic yards carried out of the estuary.
1870	Do.	9	0	27·55	
1871	Do.	9	0	33·23	
1872	Do.	8	0	50·69	
1873	Do.	7	0	28·82	
1874	Do.	7	0	30·10	
1875	Do.	8	0	35·49	
1876	Do.	8	0	36·96	
1877	Do.	9	0	41·63	
1878–82	Do.	9	0		
1883–89	Do.	10	0		

It would be seen that in 1864 there was a depth of 15 feet of water on the bar; in 1866, when there were very heavy floods down the Irwell, the depth had decreased to 12 feet. Between

1866 and 1870 there was another great change in the channels, followed by a further decrease on the bar to 9 feet in 1869. In 1872 there was a very heavy rainfall, and a very great disturbance of the sand in the upper estuary—what was termed the great fret. That continued until 1873; and it resulted in the removal of a large amount of sand from the upper estuary. The depth at the bar still decreased, until in 1873 there was only 7 feet depth of water upon it. Since that time there had been dry seasons, and few floods down the Irwell or the Mersey, so that the depth gradually increased until at the present time it was 10 feet. He thought that this justified the conclusion arrived at in the Paper, that if the sands in the upper estuary were fixed, and not allowed to roll about and wash down to the bar, there would be an advantage. Mr. Vernon-Harcourt had also referred to the Ribble. He was glad to have Mr. Vernon-Harcourt's testimony to the fact that the training-works carried down the estuary had resulted in deepening the main navigable channel. The objection he raised was that they might probably result in damage to some of the inferior channels in the estuary. Mr. Wheeler thought that that was a matter of very little importance. If by training-walls the main navigable channel up which the ships went could be deepened it mattered very little what happened to the smaller channels. Mr. Kinipple objected to a statement in the Paper, that the material on the bar came from the sea and not from the land, and in support of that he quoted certain experiments that he had made with a pail of water and a little sand, which he had poured down a trough. He thought that was rather like a storm in a teacup, comparing a few buckets of water poured down an artificial trough with what would happen in an open sea. He was not disposed to give up what he had stated on the results of an experiment of so small a character. He thought he might fairly congratulate himself that the conclusions at which he had arrived had been generally supported by the members of the Institution. Mr. Wheeler.

Sir John Coode. Sir JOHN COODE, President, said he was sure the members would agree with him that the Paper had been one of the most exhaustive character, and that it indicated an amount of reading and study on the question of the formation of bars at the entrance of tidal estuaries, of which very little idea could be formed by those who had not gone into the subject. The Author had in his Paper condensed a very great amount of information. Sir John Coode could not agree with the speakers who had laid so much stress upon the results of experiments by means of models, because they almost altogether ignored the all-important factors of

Sir John Coode. floods from the uplands, and gales from the sea. The floods, of course, all operated in one direction—down the estuary. But what happened within an estuary during gales of wind? There might be a flood or not; there might be a gale blowing strongly up the estuary, or down the estuary, and of course it required no great stretch of imagination to see that those two conditions would bring about very different results. There might be gales blowing transversely directly across the estuary from left to right, or from right to left, or there might be gales blowing obliquely at all sorts of angles. How the experiments referred to with regard to estuaries were to be taken as indications of what might be expected in nature, he for one was at a loss to understand. Then, going seaward, there were gales off shore and gales along shore, gales of short continuance, and gales of long continuance. It was not necessary to go further back than a month for an example of the latter. In January continuous gales had been blowing night and day for a fortnight. He did not know how those conditions were to be indicated by the models of which so much had been said. Those varying conditions did not come into play in the models at all. While he congratulated the Author on his Paper, he desired to comment upon one or two points in it. The Author appeared to adopt the view of Messrs. Humphreys and Abbot with regard to the Mississippi, and he had stated that "The current is able to roll the detritus along the bottom, until the river water begins to ascend upon the salt-water of the gulf, when the rolled material is left upon the bottom in the dead angle of the salt-water. A deposit is thus formed which produces the bar." He had recently met with a somewhat important Paper written by the late Captain Eads, who traversed both those statements as being founded on fallacies. With regard to sand being rolled or pushed along the bottom; he said he had gone down to the bed of the Mississippi in a diving-bell when the current was so strong that it was very difficult to get the bell down at all, and so far from finding the matter being rolled along the bottom, he could only compare it to flakes in a snowstorm. The "dead angle" was not a very apt expression. The reference was to a triangle, a wedge-shaped figure supposed to be found outside the bar. Captain Eads demolished that argument, because he gave from the appendix to the very same report of Messrs. Humphreys and Abbot the results of ten or twelve experiments; and the velocity along the sea front in those experiments indicated an average of 1¾ foot per second—more than three times the velocity necessary to move sand. It was remarkable (he said somewhat

Sir John Coode.

satirically) to find a dead angle of water which was supposed to underlie the current of a mighty river. Sir John Coode hoped that the members quite understood what he was referring to. The contention of Messrs. Humphreys and Abbot was that under the bar there was a dead angle of water. Their argument was founded upon two so-called facts, which Captain Eads called fallacies: first, that the material was pushed along the bottom; and secondly, that there was a dead angle in front of the bar. There was no such dead angle of still water, because the lowest velocity indicated in the experiments was about 0·92 foot per second, and in some cases it ran up to 3 feet per second. The Author had spoken of the material composing the bar travelling along the beach. That hardly agreed with the Abbot Castelli, who said distinctly that the principal cause of the bar was the violence of the sea; and there Sir John Coode entirely agreed with him. It had been his view, for many years, that the most important factor in the formation of bars was the power of the waves which might be exerted either in heaping up or throwing down material practically at right-angles or normal to the line of the coast. He based that statement upon what he thought was a very noteworthy fact. It might seem like ancient history, but in the year 1853 he presented a Paper to the Institution on the subject of the Chesil Bank,[1] at the end of which he gave some remarkable facts indicating the clawing down in a single night of an enormous quantity of shingle, amounting to millions of tons by actual measurement, extending over a length of about 8 miles of coast. He would take that as the basis of the figures he was about to give. He would assume a bar which was just 200 yards across from side to side, not a very large bar. And what happened? Taking the actual observations on the Chesil Bank for a length equivalent to 200 yards along the front of the beach, there were 63,000 tons moved in one night, and at the next spring-tide 45,000 tons were thrown upon the beach again. If that was not an indication of the forces of the sea in heaping up and throwing down material, he did not know what was. But there was a still more striking fact, that in a month afterwards, December, the quantity which was thrown down by the sea, in that length of 200 yards, was no less than 76,000 tons. In five days from that time the quantity heaped up was 60,000 tons. He thought that in the face of those facts the members might

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[1] Minutes of Proceedings Inst. C.E., vol. xii. p. 520.

Sir John Coode. form some idea of what the power of the sea was in dealing with material of that kind.

Mr. Wheeler. Mr. W. H. **Wheeler** said he did not understand Messrs. Humphreys and Abbot's contention in the way indicated by Sir John Coode. If he had done so he should not have endorsed it. It did not mean that there was dead water at the back of the bar—simply that it was a slackening of the current due to the action of the salt-water in forcing a way under the fresh water at that point.

Sir John Coode. Sir **John Coode**, President, said it appeared to him that the contention of Messrs. Humphreys and Abbot was as he had stated it.

Correspondence.

Mr. Baensch. Mr. **Baensch** found that the Author's treatment of the subject, and the conclusions at which he arrived, corresponded entirely with the views of German engineers who had made the subject a matter of special study. The Baltic was an example of a sea with a very small range of tide; and under these conditions the only factors in the formation of bars at the mouths of estuaries and harbours were the littoral current, which conveyed the abraded and suspended material, and the wave-movement, which deposited it upon the shore, while the counteracting agents were the outflow of fresh water and the small tidal ebb. The littoral current in the Baltic, depending upon the prevailing westerly winds, caused shoals to be deposited generally from west to east, while where the coast was sheltered from the west the usual formation was from north to south. There were few examples of fresh-water shoals, as most of the alluvial deposits from inland sources were dredged away before reaching the coast, or the current was strengthened by improvements in the channel, while in the larger harbours, such as Swinemünde, Pillau, and, above all, Memel, the deposit was effectually checked by the inner lake. In the North Sea, where there was a greater range of tide, the ebb and flow came into greater prominence as factors in the case. Outlets to the sea might be divided into two classes: first, river estuaries, such as the Weser, Ems, Elbe, and Eider, where the discharge of fresh water had to be added to the ebb-tide; and second, inlets in the coast, lagoons or meres, such as the Jahde, North and South Diep, Hever, Schmaltief, Ruytergatt, Vortrapptief, and Listertief, where, in the absence of back-water, there was only the effect of the rising and falling tide to be considered. Up to the present time there had been no necessity for artificial removal of the sand-bars at any of these places, for the depth of water was sufficient to admit of the passage of any vessels which required to enter. In many cases the flood-tide was stronger at the bar than the ebb, as, for instance, in the Eider, where the mouth of the river, with the bar, had been shifted northwards up to the point where the ebb-tide was sufficiently strong to maintain its position. In cases where the ebb-tide required greater force, this might be attained as on the Swine, by straightening or improving the channel at various places on inland reaches. Dredging was in any case only a secondary means of reducing a bar. As an example of natural scour, there occurred on the Weichsel, above Pillau, in 1855, a flood due to the accumulation of ice and the failure of certain dykes, which in the course of twenty-four hours deepened the bed of the channel to the extent of over 7 feet. Mr. Baensch.

Great attention was now paid to the protection of shores and banks, so as to limit as far as possible the surface of denudation, soft escarpments in particular being protected as far as possible from the action of the water. Captain Calver's proposition, for the construction of jetties extending into a sufficient depth of water to check the erosive action of the waves, was not on the Baltic and northern coasts likely to be attended with sufficiently decisive results, for the mass of material conveyed in suspension by the littoral currents was so great, that even beyond the point where the bed of the sea was directly affected it was swept within the surface of action of the waves, and so carried back to the shore to be deposited on the bar.

Mr. P. CALAND had read the Paper with great interest, and was able to accept the Author's conclusions as being in accordance with the opinions he had arrived at after many years' experience. He was of opinion, that the formation of a bank or bar at the mouth of a tidal river was due to the action of the flood stream, and that the only method of removing it was by utilizing the scouring power of the ebb current. Every impediment to the free entry of the flood tide should therefore be removed, in order to obtain the largest possible volume of water for the return current, which should be guided in the direction of the required channel over the bar into deep water. The guide-walls for this purpose need be of no great height, as they were only required to give a lead to the ebb, which could be as well done by half-tide walls, as by those of greater height, which were very costly in maintenance, and the same remark applied to the training-walls in the upper reaches, if Mr. Caland.

Mr. Caland. the rivers were required to hold up the flood water, so as to give the necessary scour for maintaining the deep channel on the bar. In order to facilitate the indraught of the flood, the river mouth should be essentially funnel-shaped, and the direction of the walls over the bar should conform to it. This was a point of principal importance, and, generally speaking, it might be said that the same form should prevail over the entire portion covered by the flood, which should be of greater breadth than the channel above the tidal influence. These general principles had been applied in the improvements of the water-way from Rotterdam to the sea, which were begun in 1863, and were now for the most part completed. The Hoek van Holland was now replaced by a new river mouth, which was carried out into deep water by training-walls; and in the spot where cattle pastured in 1868, there was now a sea channel from 600 to 700 metres wide (1,645 to 1,920 feet), with a depth of about 30 feet at high-water, by which steamers were enabled to reach the quays of Rotterdam from the open sea in two hours, instead of being delayed for two days or more, as was formerly the case with the greater number of ships of deep draught.

Mr. Cay. Mr. W. Dyce Cay believed that all rivers which had their outlet into the waves of a tidal sea had bars, whilst those which emptied into inlets or firths of the sea were protected from wave action, and so had no bars, such as the Clyde, the Severn, and the Forth. The first class might be called unprotected and the second protected outfalls. Where there was sand and a confliction of currents, with waves, a bar was produced. The deposit might take place either during the ebb or the flow of the tide, or during slack-water; during the ebb there was always a flow of sand more or less in quantity along the bottom seawards, and the bottom salt or brackish current was generally more sluggish than the fresh surface-water. Thus he had found at Aberdeen, when the river was full but not flooded, that floats reaching 2 feet in depth travelled seawards twice as fast as those reaching to 12 feet below the surface. The floats were wooden rods passing through corks at the top and fixed in weighted elm blocks at the bottom. No doubt sand was carried down the River Dee, as many thousand tons of it had to be dredged annually from the part where it entered the deeper tidal channel of the harbour; also it had been reported to him by divers, engaged in constructing the North Pier Extension, that the sand accumulated on the north or seaward side of the concrete work, and not on the river side, as if from a flow outward; and he had himself observed, when down in the helmet diving-dress off the end of the South Breakwater, the sand moving along in the current, like fine drifting snow, out of the harbour. He thought that the breakers drawing up this sluggish current of ebbing sand, and throwing it back repeatedly as they broke, would be sufficient to cause a bar. During flood-tide also the banks of sand lying outside the harbour would be drifted towards the bar; thus at Aberdeen the flood-tide flowed from the north across the harbour mouth with a maximum speed of 1 knot per hour, and would bring sand from the Ythan and the Don rivers and the sandy coast there; it passed into the harbour under the fresh water with a maximum speed of ½ knot per hour, and in storms the sand stirred by the waves would thus be drifted and deposited where the waves broke on the bar. During slack-tide the sand on the bar would be further consolidated by the passage of the waves over it. It became so solid at Aberdeen, that felt with a sounding-rod it seemed like rock, and it was quite intelligible how scouring currents carrying sand and detritus might pass and repass without removing it. The bar at Aberdeen was of a fine sand consisting of quartz, mica, and fragments of shells, with a small proportion of cinders or coal (probably from the dredgers), and traces of sewage coming from the outfall of the town sewers. It was similar to the sand on the adjoining bed of the sea, and was all uniform in appearance and fineness. It was heavy, and after being shaken up in water immediately subsided. About 40,000 tons were deposited annually, which had to be removed by dredging. The phenomenon of a deep hole or part without silt at the inside of the bar, shown in the Paper as occurring at the Mersey, the Ribble, the Tees, and the Liffey, was, he thought, probably caused by the dense salt-water of the flood-tide rising up to the top of the bar on its sea side, then flowing down its landward slope like a submarine rapid under the brackish ebbing water, and thus scouring out a hollow at the foot and depositing sand to form a ridge beyond. As to remedial measures, the object was to avoid having a locality where breakers were produced by the confliction of waves and currents, or by shoal ground or narrowing of the outfall channel; this pointed to dredging and widening the channel at the bar; and as the tendency of a bar once begun was to aid in its own accretion, the occasional dredging would much retard its progress. Also its protection by a breakwater, or by enclosing arms, or by directing the current so as not to stem the waves, would evidently conduce to the same end; thus, in addition to the protected outfalls mentioned above, Plate 1, Figs. 1 and 7, showed that the outfalls of the Thames, the Humber, and Lynn Deeps, Mr. Cay.

Mr. Cay. which had no bars, did not directly breast the waves of the North Sea, but rather inclined shorewards and were protected, the Thames and Lynn Deeps by sandbanks or shoals, and the Humber by Spurn Point, from the easterly rollers. Another advantageous measure was the cutting off of the sources of supply of sand, such as the diversion of upland or river water out of an estuary where practicable. Besides removing a source of sand this would do away with the useless surface-current of fresh or brackish water, which tended to form breakers, and which weakened the scouring power of the ebb current, which but for the fresh water would have the same density as the salt flood-water, and would have more power in removing the bar; also the carrying out of piers, groynes, or breakwaters, so as to cut off shallow sandy parts of the sea bottom from the channel and the bar, would stop the accretion of sand from seaward sources of supply.

A remarkable feature of deep-water bars which he had noticed was their crests having, when uninfluenced by artificial scour or dredging, a tolerably uniform level with reference to low-water, say 6 to 12 feet below low-water of ordinary spring-tide, and this with great variation in the velocity and depth of the ebbing current. He thought this showed that the limitation of the height, to which the bar had a tendency to rise, was due to the effect of the waves stirring it up and the current removing it if it rose higher, and that once deposited the ordinary ebbing current had little effect on it.

Mr. Cunningham. Mr. D. Cunningham noted the Author's statement that "the material of which bars are formed consists of coarse sand, the particles of which are too large to be carried in suspension," and his belief that the vast masses of sand which encumbered some parts of the coast, were probably due to torrents arising from the melting of enormous masses of ice at the close of the Glacial period, and remarked that the first of his formal conclusions was that bars were caused by influences from the sea, not from the landward water. It was difficult to reconcile these statements with others he had made, such as that in a river the ebb had "just so much preponderance as enables it to carry away and dispose of the detritus brought down to the estuary by the upland waters," and that the material in an estuary always ultimately progressed downwards. Mr. Cunningham agreed with these last statements. He had found in the estuary of the Tay that the progress was steadily downwards, slowly in the wide upper estuary, rapidly in the narrow lower estuary. The material forming the banks in the estuary of the Tay consisted of sand of different degrees of coarseness. The banks in the converging lower part of the upper estuary moved down faster and faster as they approached the "throat," which commenced somewhat below the harbour of Dundee. Then, the currents intensifying as the banks still further converged, the sand no longer remained as banks, but was carried, with a force of ebb-tide greater than it had previously been subjected to, rapidly onwards toward the bar at the entrance to the river. In such movement the sand must be more or less in suspension, though, from observations made, the great bulk of it had been found in motion close to the bottom. Vast quantities of such sand had been carried down the river from that part of the estuary immediately above the port during the past fifty years, as had been ascertained from actual survey and careful comparison. No accumulations had taken place in the lower part of the estuary, where the currents ran most rapidly; but the sand had, generally speaking, been swept down to the bar. Instead of the immediately contiguous shores of the sea parting with materials to form the bar, the sands of the river, partly deposited on the banks between high-water and low-water mark, had contributed, through the agency of the winds, to add to these shores, extending them seawards in the form of bent-grown links. He was of opinion that all the influences acting upon the bar of a river must be taken into account, and the influence of the landward water could not be neglected. Indeed, did it not form the most important influence in that movement which the Author alluded to as "always ultimately progressing downwards?" In the upper estuary of the Tay, the flood-tide ran at a more rapid rate than the ebb, but then it ran up-hill against the accumulating landward water, whereas the ebb ran down-hill with it. In the lower part of the estuary, where the currents of flood and ebb almost balanced each other, what influence could preserve it from being choked up in course of time if the landward water did not supply that superior force, more especially in the time of floods, which enabled it to send the material downwards? The lower part of the estuary differed from the upper in this, that, the bed of the river for 10 miles being roughly level, gravity did not assist the ebb-tide; it must be absolutely stronger than the flood, in order to produce the effects which it did. He therefore differed from the Author in his formal conclusion (1), "That the causes which operate in maintaining the existence of bars in tidal estuaries come from the sea, and are not due to the inland water." There was another point of some interest with reference to the manner in which sand behaved on and about a bar. The Author said that "the heavy particles of sand are rolled by the current

Mr. Cunningham.

Mr. Cunningham. up the slope and over the ridge, the form of the slope and action being reversed on the turn of the tide." The slope of a bar seawards was long and steep, and it was difficult to understand how the sand, once driven over upon such a slope, could be driven up again by the flood-tide. Did it not seem more likely that the great proportion remained quiescent, and did not return, and that the continual accumulations accounted for the seaward progression of the bar? With reference to the effect of reclamation works in an estuary, he considered that the Author said much of value, all the more so that it was in opposition to the general view of the profession. He held that it would be "a mistake to condemn" such works under all circumstances. He referred to what Mr. Cunningham had said in his "Report on the River Tay," dated December 1887. That report showed that a large cubic content had been abstracted from the area of the estuary during the previous forty-three years by natural deposit and artificial reclamation; but that the increase in the flow of the tidal wave had more than made up for such abstraction. The bed of the river, more particularly in the vicinity of the harbour, had been thereby materially deepened. But the most prominent improvement had taken place upon the bar, which had been during all that period continuously deepening, and now the depths upon the bar, and contiguous sands, were more by a considerable number of feet (generally 2 to 8) than they were at the beginning of this period. In the very highest part of the estuary, where the river was narrow, excavations had been made about fifty years ago, with the view of improving the navigation to Perth; but being relatively small in quantity, and necessarily, in general, below low-water mark, the influence of such works could only have been infinitesimal. Moreover, the greatest amount of improvement at the mouth of the river had taken place of late years, long after such works had been completed. There could be no doubt, therefore, that it did not always hold good that when abstractions, natural or artificial, took place in an estuary, the result must be prejudicial to the bar. The effect of such works largely depended upon the line of frontage carried out, but more largely upon their position (up or down) in an estuary; and, as in the Tay, it might turn out that a new line in a proper position in an estuary, whereby the channel, naturally too wide and straggling, was restricted in width, might much improve such channel, and thereby indirectly the general regime of the river.

Mr. Griffith. Mr. J. P. GRIFFITH observed that in 1879 he communicated a Paper to the Institution on the "Improvement of the Bar of

Dublin Harbour by Artificial Scour,"[1] when most of the points raised in the present Paper were touched upon, either in the Paper or in the following discussion. References were made to the various causes which had produced bars, the relative value of upland and tidal water, the importance of tidal water, and the dangers of reclamation. In the case of Dublin, the advantage of the total absence of a training-wall on the north side of the channel, and the value of a diffused flood and concentrated ebb over the bars were pointed out. The Author had not, however, limited the Paper to bars, but discussed the principles of training rivers through tidal estuaries. It would seem that his ideal channel through an estuary was that of the form shown in *Fig. 1.* If the only aim were to form a channel without a bar, this object might be attained by training-walls properly designed on the principles laid down by Mr. L. F. Vernon-Harcourt in his communication to the Royal Society in February 1889. But the interests of navigation sometimes necessitated a departure from these lines. The tapering channel, if scientifically trained, might be free from a bar, but it would probably diminish in depth as well as in width in proportion to the distance from the mouth. At the same time, it was particularly defective in affording shelter to vessels entering during on-shore gales, and its very form tended to augment the height of the waves. This form of channel was proposed by Captain Bligh, at the beginning of the present century, for the improvement of the approach to Dublin Harbour. The proposal was supported by the Tidal Harbour Commission in 1846, twenty-five years after the completion of the Great North Wall, and had its advocates even in 1879. Nevertheless, Mr. Griffith still firmly believed that the works, as constructed, had proved more beneficial to the Port of Dublin than if Captain Bligh's funnel-shaped channel had been adopted. He based this conclusion on the great additional volume of tidal water concentrated on the bar by the present works, the increased shelter afforded to the port, the facility given for improving the channel inside the bar by dredging, and at the same time increasing the tidal capacity of the port. Some of the Author's remarks as to reclamation of indents and irregularities in the coast-line of an estuary needed qualification. He advocated such reclamation on the grounds that it would "conduce to the free flow of the tidal wave into the upper reaches." Now in Dublin these remote strand-areas were of undoubted value. The great object there was to increase the tidal volume

Mr. Griffith.

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[1] Minutes of Proceedings Inst. C.E., vol. lviii. p. 104.

Mr. Griffith. discharged across the bar after half-ebb. Under ordinary circumstances the tidal gradient was at its maximum about half-ebb, or, as the Author said, "During this period the tide falls nearly twice as fast as during the first and last quarters." In Dublin Harbour tidal water flowed off the strands into the navigable channel inside the bar, and it was found that the water from the more remote portion of the strand did not reach the channel till considerably after half-tide, thus keeping up the head of water in the channel inside the bar, and increasing the efficiency of the scour after half-ebb. For this reason, any encroachment on the tidal area, of even remote and high-level strands, had been strenuously resisted in Dublin. At the close of his communication the Author stated that from the facts and opinions given in the Paper, he considered he was justified in formulating four statements or propositions, which he seemed to treat as general conclusions. It might be useful, and it certainly was legitimate, to test such conclusions by the light of existing works, which had proved successful. Mr. Griffith would therefore ask how far these four statements were in unison with the known facts regarding Dublin bar, and the works carried out for its improvement. In regard to statements 1 and 2, the lessons learned from Dublin bar confirmed the Author's views; while in the case of 3 and 4 the works constructed for the improvement of Dublin bar were not designed on the principles laid down by the Author, and yet had proved eminently successful. Mr. Griffith, in concluding his Paper on the improvement of Dublin harbour, drew attention to the necessity for great caution in adopting similar works elsewhere. He regretted that the Author had formulated his conclusions in such a manner that a student might accept them as an infallible guide for the treatment of bars at the mouths of tidal estuaries.

Mr. Kidd. Mr. W. KIDD observed that many of the points touched upon in the Paper received practical illustration in the case of Blyth Harbour, Northumberland, where a bar had been recently successfully removed. This harbour was situated on a sandy coast at the mouth of the River Blyth.[1] In 1881 works for its improvement were undertaken. The piers extended only to a little beyond low-water mark of ordinary spring-tides, and the harbour entrance was much obstructed by a bar, the depth over which varied between 1 foot and 4 feet below low-water of ordinary spring-tides; the former after every south-east storm, and the latter after the summer dredging had been completed. The range of spring-tides being

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[1] Minutes of Proceedings Inst. C.E., vol. xxi. p. 322; and vol. lxxxi. p. 302.

Mr. Kidd.

14 feet 6 inches gave high-water depths of 15 feet 6 inches and 18 feet 6 inches respectively, and about 4 feet less at neap-tides. The cause of the formation of the bar was obviously due to the wave-action in south-east storms, inasmuch as soundings over the bar had, on many occasions, shown a diminution from 3 feet 6 inches or 4 feet below, to 1 foot or 1 foot 6 inches below low-water of spring-tides, to have taken place in the course of a single storm of only two or three days' duration; while during calm weather the depth of 3 feet 6 inches or 4 feet had been maintained for months at a time, although freshets in the river occurred during the same periods. This also showed that no material movement of the bar was attributable to the action of the littoral currents. Further, the bar was composed entirely of clean sea sand of exactly the same kind as that which formed the bottom of the bay outside, and the beach for some 2 miles to the south. The river was subject to heavy floods, and its banks within the limit of tidal range, extending some 5 miles inland from the bar, were covered with thick deposits of soft mud. This mud was carried away in suspension by the flood waters in large quantities, yet none was ever found in the neighbourhood of the bar. Up to this time almost the whole of the bed of the estuary was dry at low-water of spring-tides, there being then only the upland water flowing down the channel. These observations left no doubt as to the causes of the formation of the bar. In contrast to this state of things it might be said that there was now no bar at the entrance. The improvement works were commenced by the removal of a large area of rock dry at low-water,[1] which extended nearly across the river at a point about 1 mile up from the entrance, to a depth of 15 feet below low-water. The effect of this was at once felt, in affording freer scope for the flow of the tides, but it was understood that no material improvement of the bar need be looked for until the piers were extended, and the hard material in the channel below had been dredged. It was proposed to extend the piers seaward 1,000 feet further, into a depth of 10 feet below low-water of ordinary spring-tides, and to dredge the channel from the point where the rock had been removed out to the new pier-heads, from about 3 feet below to 10 feet below low-water mark, most of the material being hard shale and rock. Of the proposed extension of the piers a length of only 300 feet was completed in the first instance, and the channel was dredged for a width of 90 feet to a depth of 12 feet below low-water. At the same time the tidal receptacle had been

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxi. p. 302.

Mr. Kidd. further materially enlarged by the dredging of extensive deep-water berths in the inner harbour to 18 feet below low-water. With the completion of these works, the bar had practically disappeared, there being now a clear channel to sea having 12 feet depth at low-water, with a tendency to scour rather than to silt up, between the new pier-heads. The extensive dredging formerly required to keep the bar down to only 4 feet depth below low-water had practically become unnecessary. It was remarkable that these results were achieved by an extension of the piers of only 300 feet, which placed the heads into a natural depth much less than 12 feet at low-water, owing to the slope of the sea bottom. These works had been executed at a low expenditure. For the purpose of affording further shelter to the entrance channel, the east pier was subsequently extended a further 100 feet. It might be stated, incidentally, as an example of the commercial value of deep water, that the shipments of coal at the port had increased from 150,000 tons annually prior to the completion of the channel, to 1,500,000 tons at the present time; and that whereas the largest cargo was formerly limited to about 1,500 tons, vessels carrying between 3,000 and 4,000 tons had safely passed to sea since the completion of the works referred to. In the case of another harbour on the Northumberland coast, Warkworth, at the mouth of the River Coquet, similar causes were responsible for the formation of a bar at the entrance; indeed, the similarity of conditions to those at Blyth was remarkable; the bar being formed of sea sand thrown up by the waves during on-shore gales, and the river being similarly liable to heavy freshets carrying much suspended matter. Works designed on like principles as those executed at Blyth were proposed for the improvement of the sea-channel and bar. Other East Coast estuary harbours, with which he was acquainted, exhibited precisely the same causes for the existence of the bars at their mouths: in some of them, works were in progress for the improvement of their entrances, which, though differing much in minor points according to the circumstances of each case, were all designed on the broad principles of extending the piers into deep water, and enlarging the tidal receptacle within. Though not an estuary harbour, he might refer to a harbour which he was now constructing on a sandy coast near Saltburn-by-the-Sea for an illustration of the movement of sand on the sea-bottom by storm waves. Though the littoral currents, owing to the embayment of the site, were practically *nil*, the surface of the sand changed in level as much as 3 feet at some points seaward of low-water mark; and on the foreshore between high-water and low-water levels, changes occurred with every on-shore gale, amounting sometimes to as much as 6 feet difference of level over an immense area. Mr. Kidd.

Mr. L. Luiggi, of Genoa, said that in the Mediterranean, where there was an exceedingly small range of tide, the problem of the formation of bars at the mouths of rivers presented itself under a much simpler aspect than in seas with great tidal variation and strong currents. It was, however, only in recent times that the movement of sand on the Mediterranean coasts, for many centuries a subject of great controversy, had been adequately explained; and the whole old theory that the movement of the sand was due mainly, if not entirely, to littoral currents, had now been abandoned. It was now, on the contrary, generally admitted that the formation of bars in river estuaries and narrow harbours, and the shoaling up of the shore-line, were due chiefly to the action of the waves, the tendency of which was to deposit sandbanks all round the coast; the chief counteracting force being the discharge of inland waters and tidal estuaries into the sea. The opinions of Italian hydraulic engineers of great authority, as Mr. Parodi, Mr. Mati, and Mr. Cornaglia, coincided fully in this respect with those expressed by Captain Calver, Mr. Stevenson, Mr. Vernon-Harcourt, and the Author of the Paper. The plan of reducing the width of an estuary by means of jetties or breakwaters, so as to confine the current in one somewhat restricted channel, had been employed with tolerable success in many small river-ports, as at Porto Corsini, Rimini and Pesaro on the Adriatic, and at Viareggio, Fiumicino and Regi Lagni on the Mediterranean. These jetties were, however, not carried out into a sufficient depth of water for the waves to lose their scouring effect on the sand-beds, so that the silting up process had not been completely arrested. If these jetties were extended to a depth of from 25 to 30 feet of water, at which depths (according to the configuration of the shore) the waves of the Mediterranean, even in the severest storms, lost much of their scouring or abrading effect, the results would be much more satisfactory, and would probably compare with the cases of rivers in Great Britain referred to by the Author, where the tidal currents, and especially the ebb, had a beneficial effect. Unfortunately, none of the estuaries of the great rivers of Italy were provided with works carried out on the scale referred to; but the improvements already effected and still in progress on the passes giving access to the Lagoon of Venice had been attended by results fully satisfying all the requirements of navigation. As was well known the great Lagoon at present was fed only by Mr. Luiggi.

Mr. Luiggi. water from the Adriatic, the rivers which formerly discharged into it their alluvial deposits having been diverted by artificial channels to the open sea. The Lagoon was therefore a great salt lake, communicating with the sea by five channels, called "ports," the most important of which were the ports of Chioggia, Malamocco and Lido. The average range of tide in the Lagoon was 2 feet, and the maximum 4 feet; and the tidal currents were the only force opposed to the silting action of the waves, especially under the set of the prevailing winds. The two channels nearest to, and therefore more immediately affecting, Venice itself, were the ports of Malamocco and Lido. Before the commencement of the improvement works these were both approached by tortuous, shallow, and irregular channels, and endangered by long sand-bars. The average depth of the channel over the bar at Lido was only between 8 and 9 feet, which absolutely blocked all access to large sea-going vessels; while the long channel through the Lagoon southwards to the Porto di Malamocco had a depth of 25 feet, reduced at the Malamocco bar to 10 feet, and this was the maximum depth of water available for any approach to the quays of the city or to the dockyard. The entrance at Malamocco was first taken in hand, and the two parallel jetties were constructed, of which that on the north side, exposed to the action of the littoral current and the prevailing north-east winds, and designed therefore to check the silting action, was carried into 28 feet of water; while the south jetty, designed to diminish the width of the channel and therefore to increase the tidal scour, terminated at the depth of 17 feet. The result of these works had been that the depth of the navigable channel had increased from 10 feet to 28 feet, and this depth was maintained by the natural action of the water alone, without any dredging or excavation. At the Porto di Lido the works were still in progress and promised still better results. They were designed on the same principles as the former, but with a little variation. The two jetties were not parallel but slightly convergent, and curved with their convex sides turned inside, so as to decrease slowly and regularly the width of the channel, and increase the scouring action of the tidal currents at the entrance. Owing to the pressure of public opinion in Venice, where fears were expressed as to the disastrous effects of possible failure of the works, one portion only, the northern jetty, running out to a depth of 28 feet, was first sanctioned and effectively carried out. The result of even this fragmentary work had been so conclusively successful, the channel, though still unlimited in width, having increased in depth from

Mr. Luiggi. 8 feet to about 20 feet, by scouring action alone, that the construction of the southern jetty, extending into 17 feet of water, was now in active progress. Upon the completion of the improved channel, the anticipations of increasing the depth of waterway to 28 or 30 feet could hardly fail to be realized.

Mr. Mann. Mr. I. J. MANN thought that the large number of bars and estuaries referred to in the Paper had, in most cases, been touched upon too lightly for practical purposes. Of the four classes into which bars had been divided by the Author, the first might be eliminated, the required excavation being effected as mechanically and permanently as that of an ordinary railway cutting through the same kind of material. Class 3 might be regarded as a particular case of class 4, and did not seem to require separate consideration. The subject would be further narrowed and simplified, so far as engineers were concerned, by defining a bar as a shoal or bank extending across the entrance channel, having deeper water landward and seaward of it, the depth upon it at low-water being such as to impede navigation, the amount of obstruction to be measured not by the height of the shoal above the adjoining bottom, but by the available depth upon it at low-water. He agreed that a bar and a delta were two distinctly different things, and it seemed in every way desirable that they should not be confounded with one another. The failure to get rid of the bar at the mouth of the Rhone had shown that the successful application of scour depended on the sufficiency of the currents seaward of the bar to take up and disperse in deep water the material removed by the scour. The depth to which the action of moderate-sized waves extended, and the amount of their effects on the material composing the bottom, was a part of the subject on which additional information was desirable. With reference to the action of the sea on sandy beaches, at Rosslare, on the east coast of Ireland, he had not unfrequently seen quantities of fine sand, estimated at from 15,000 to 20,000 tons, carried away by a single tide in easterly gales from a length of less than ¼ mile of the shore. Nearly the whole of this sand was removed from between high-water and low-water mark, and deposited in a similar position on the foreshore further to the northward. The action of the sea on the coast at Rosslare was confined to very shallow water; seaward of a depth of from 8 to 10 feet at low-water no alteration in the bottom could be detected. This, however, was no doubt due to the extremely sheltered position of that part of the coast from the prevailing wind. In his remarks on the bar of the Mersey, the Author gave the present depth upon it at

Mr. Mann. low-water spring-tide as 9 feet, which was 1 foot less than stated by Mr. Lyster in his recent Paper [1]; and as this bar was likely to affect interests of the largest magnitude, any statements made with respect to it were naturally regarded with more than usual attention. Referring to the bar at the mouth of the Liffey, the following statement of the Author required some modification:—"The increased scouring action lowered the bar 5 feet in the first ten years" (from 1819 to 1829). "The deepening has since continued, although at a less rapid rate, the total gain having been 12 feet." What had actually taken place was shown by the following Table:—

Date.	Minimum Depth on the Bar at Low-water Spring-tides.		Authority.
	Feet.	Inches.	
1819	6	6	F. Giles.
1822	8	6	Telford.
1828	9	6	Frazer.
1856	13	0	Wright.
1873	16	0	Kerr.
1880	16	0	Langdon.
Total gain . .	9 feet 6 inches.		

Since 1880 there had been no increase in the depth, but, he believed, rather the contrary. It appeared, therefore, that the scouring action of the induced current reached the limit of its deepening power seventeen years ago, and had since been hardly sufficient to prevent shoaling. With reference to piers carried out seaward from the shore, he thought it would be hazardous in most cases to project a solid structure across the littoral current, even if that structure was extended into comparatively deep water.

Mr. Messent. Mr. P. J. Messent, without expressing approval of all the theories enumerated by the Author, was glad to acknowledge the indebtedness of the profession for the information given in the Paper, although he disagreed from some portions of it. The Author stated (p. 121), "The bars that formerly existed on the Tyne, on the Tees, and on the Ribble, cannot be regarded as impediments affecting the navigable depth of water, inasmuch as the depth in

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[1] Minutes of Proceedings Inst. C.E., vol. c. p. 6.

the channel, a short distance above the bar, is as shoal or shoaler than that on the bar. On the Tyne (Plate 5, Fig. 13) the depth outside the bar, in 1860, at low-water of spring-tides, was 50 feet; on the bar it was 6 feet; at ½ mile inside the depth increased to 12 feet, and at 1 mile to 30 feet. It then shoaled to 4 feet 6 inches, deepening again to 32 feet 6 inches, and shoaling again to 6 feet just below the entrance to the Tyne Dock, about 2½ miles above the bar, so that the depths on the bar and in the channel were nearly the same." Now in the case of the Tyne, although in the centre of the channel, where the depth in the present channel was shown (Plate 5, Fig. 13), there was in 1860 a depth of only 4½ feet at low-water; there was at that time, north of the centre, as would be seen by an examination of the Admiralty ("Calver's") Chart of 1857, a deep-water channel and mooring space, varying from 23 feet to 10 feet at low-water of spring-tides, extending from the Narrows, about 1 mile from the bar, to the entrance to Tyne Dock, about 1½ mile further up the river. In this portion of the River Tyne, known as Shields Harbour, hundreds of laden vessels were able to lie afloat at moorings, waiting for a favourable tide to enable them to get over the bar to sea. The former Tyne bar must therefore be regarded as an impediment affecting the navigable depth of water, as frequently preventing fleets of vessels, lying moored and ready within a short distance of it, from proceeding to sea, when without "such impediment" they would have been able to do so. The same observations, although in a less degree, applied to the Tees, where vessels used to anchor or moor in deep water within the bar, awaiting sufficient depth of water to pass over it. The bar there, also, was a hindrance to the navigation. In the Ribble the case was similar, but on account of the very large and consequent rapid rate of the rise and fall of tide at the entrance, the impediment caused by the bar could not properly be measured or estimated by the depth below a fixed level of a portion of the navigable channel a few miles above, compared with that on the bar. Therefore, whilst the bar was an impediment to vessels anchored or moored in the deep-water pool between it and the shoal next above, for vessels going down from Preston to the sea it was also an impediment on an ebb-tide, as such vessels (passing safely, without much to spare, over the shoal, 6 feet 6 inches below low-water, at 2 miles above the bar) would require from 2 to 3 feet more water below the same level to pass safely over the bar, where, according to the Author's statement, there was a depth of 6 feet, or from 3 to

Mr. Messent.

Mr. Messent. 3½ feet less than required. He might state that in 1888 he found less water on the bar of the Ribble than that given by the Author. As to the works for the removal of bars (p. 138), in the case of the Tees he was of opinion that the deepening of the bar and of the channel above was due more to the effect of the flood-tide with seas from the north, conducted into the harbour by the projection of the South Gare breakwater, than to the training or contracting of the low-water channel, which was about twice as wide at the outer end of the breakwater or entrance to the harbour as it was a mile above. In the Tyne, with which he was more intimately connected, he should explain that the 83,000,000 tons of sand and other material, which the Author stated had been removed by dredging and carried out to sea, included the deepening of about 15 miles of river above the former site of the bar; and although this deepening and other works had allowed 16,000,000 cubic yards of additional tidal water to enter the estuary and river, and had caused a great increase in the velocity of the tidal wave, it had diminished the velocity of the tidal current on the ebb-tide, as well as on the flood-tide, on account of the increased volume of water always remaining below low-water. The deepening of the bar could not, therefore, properly be attributed to the increased scouring-power of the ebb. The sand of which the bar was composed had been removed by dredgers, which were enabled to work under the protection afforded by the projection of the piers. As these advanced into deep water, the further entrance of sand from the outside gradually ceased, whilst the northerly seas, with the flood-tide, scoured out and deepened the shoal between the navigable channel and the south pier, the sand so scoured being deposited in, and north of, the above channel, from which it had been several times removed. As the space between the channel and the south pier had become deeper by from 14 to 18 feet, the further shoaling of the channel had apparently stopped from the failure of supply, the sand being less easily moved as the depth increased. He did not agree with the Author that the successful results of the Tyne piers designed by the late Mr. J, Walker, Past-President (the original survey and drawings having been made by Mr. Messent under his direction, in 1855), were due to, or in accordance with, the writing or theory of Captain Calver, R.N. Instead of the sand from the outside accumulating along the piers, and causing the bar to form again in front of them, there had been a great deepening outside the site of the former bar and the pier-heads, as shown in Plate 5, Fig. 13. So far from Captain Calver approving of the original design of the Tyne piers, in 1858 he gave the following evidence before the Royal Commission on Harbours of Refuge[1]:— Mr. Messent.

"28,411. My estimate is that, with Mr. Walker's original projection, there might ultimately be upon the bar a depth of about 10 feet, and with the enlarged plan ultimately about 11 feet.

"28,412. And that the bar would remain about the place where it now is or thereabouts?—Distinctly not; it would be between the pier-heads, wherever they may be placed.

"28,413. Do you mean to tell us that if we carry out the piers to 37 feet at low-water, that in course of time it will fill up so as to have only 10 feet or 11 feet of water there?—That is my opinion.

"28,415. Then if we carried out the piers to 60 feet, do you mean to tell me that the bar would be carried out too, and that there would be but 10 feet water where there was 60 feet when the piers were constructed?—I do not like to say 10 feet or 11 feet exactly. The only difference would be due to the amount of the tidal water you admitted in your enlarged works, to produce an increased depth. I am prepared to say that if it were possible to take these piers out to 60 feet water, in the process of years you would have the bar restored there with only 10 feet or 11 feet of water over it.

"28,416. You mean to say that if we carry out the piers to 60 feet, in the course of time the bar would also be carried out, so that you would only have 10 feet water, where there is now 60 feet?—I think so; 10 feet, or a little more, as the case may be.

"28,417. If you were to carry them out to 100 feet, what would be the consequence?—If there was a sufficient supply of the coast drift, you would have the same thing restored there with the extra depth due to the extra enclosure of tidal water.

"28,418. Then, if you carry them out to the middle of the North Sea, it seems to be a mere question of time. The bar that was at the mouth of the river would be carried right out to these pier-heads?—Yes, as a broad principle, that is the fact.

"28,428. But if the Tyne was deepened to 20 feet at low-water at its entrance, would not that be the means of saving a very large amount of the lives and property which are now lost in the bay in south-easterly and easterly gales?—I can only answer that question with respect to my belief in its feasibility. I do not believe it to be possible at all."

The present depth of water at low-water of spring-tides over the former site of the bar was more than 20 feet.

Mr. THOMAS MILLER, Engineer to the Commissioners of the River Orwell Dock and Port of Ipswich, remarked that the views of the Author as setting forth the lessons to be taught in the examination of estuaries having deep-water channels, and so incidentally describing the conditions which should surround a navigable estuary in a perfect condition as to conservancy and tidal flow, appeared to him to have a peculiarly fit application to the River Orwell. This estuary debouched into Harwich Harbour by a confluence with that of the Stour, whose tidal storage capacity was Mr. Miller.

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[1] Vol. ii. Minutes of Evidence, p. 857.

r. Miller. probably more than double that of the Orwell, so adding greatly to the volume and speed of the flood and the ebb currents which traversed the harbour, scouring and maintaining in co-operation with the Harwich Harbour Conservancy Board's works, a deep-water entrance from the sea, which was ample in proportion to the requirements of the Orwell. The flood-tide frequently came in from the sea highly charged with sediment, and sweeping round the curved fairway of the harbour towards the larger receptacle of the Stour, entered, in an easy tangential direction, the mouth of the Orwell, where its velocity was appreciably diminished, and the sediment mostly thrown down within the first 1½ mile. The low-water channel of the Orwell for the first 7 miles from the harbour, commencing with 22 feet at ordinary low-water of spring-tides, and a width of 200 fathoms, was still in a natural state, no dredging having ever been executed in it. It had a gradually and uniformly diminishing width, and the bed a nearly uniform gradient of about 1½ foot per mile, throughout which the flood-tide was uniformly propagated without injurious or even appreciable scour; and no sufficient disturbance had been found within the last thirty years to create any inconvenience to navigation. For the remaining 2½ miles, the channel, commencing with 11 feet and terminating with 8 feet depths at low-water of spring-tides at the Port of Ipswich, might be considered mainly artificial, steam dredging having been carried on since the year 1806, and with increased and more powerful plant during the last ten years, resulting in a channel averaging 50 fathoms in width, of greatly improved contour, the ancient and natural channels having been either trebled in capacity or obliterated by improved straight cuts. The marginal width of ooze flat for this upper portion bore nearly the same proportion to the width of channel as in the 5 miles next below it (4 times); so that upon the tide reaching at about one-third flood (or Ordnance Datum) the point of overflow of the flats, its momentum was relieved by their overflow and undue and injurious scour prevented, except at two or three of the bends, which were in process of being cut off, following the recommendation of the late Mr. J. F. Bateman, Past-President Inst. C.E. The upland waters, except in time of heavy rain, were so inconsiderable in comparison with the tidal volume, that no notice was taken of their operation save in the somewhat narrow artificial channel above the dock entrance, and at its discharge into still deep water, where accumulations of silt took place and were removed by dredging. The depth of water on the dock-gate sills, and in the channel contiguous to the dock entrance, was 10 feet. Ordinary

Mr. Miller.

spring-tides rose 13 feet 8 inches at Ipswich, and 12 feet 4 inches at Harwich. High-water at Ipswich was not perceptibly stationary, and was raised about 10 inches above the summit level at Harwich by momentum; low-water was also depressed below that at Harwich about 6 inches from the same cause, and appeared to be nearly stationary from thirty to forty minutes. This was ascertained some years ago, by reducing to Ordnance Datum simultaneous observations of the rise and fall of spring-tides at Ipswich and at Felixstowe pier in Harwich Harbour, during its construction by himself. It would be observed that the range at Harwich was 10 inches in excess of that established by the Admiralty in 1843; but the re-survey of the harbour under the direction of Staff-Commander Parsons, R.N., in 1872, established the fact that the Harwich Harbour Conservancy Board's works had so far trained and improved the entrance, that the tide ebbed from the harbour at least the 10 inches lower, which he had experimentally ascertained as above stated. The duration of the flood-tide in the upper reaches of the Orwell was six hours and three-quarters, and of the ebb five hours and three-quarters. High-water was thirty minutes later at Ipswich than at Harwich, but low-water only fifteen minutes, the latter sometimes almost simultaneous, owing, probably, to a restoration in the upper channel of the balance lost by momentum, which appeared as an early flood motion, but was due only to oscillation. The free exit of the water from the lower reaches gave to that in the upper a momentum which continued to act upon the reduced volume in the channel, after the drying of the flats at two-thirds ebb, to a sufficient extent, it was surmised, to account for the low-water depression at Ipswich and its early occurrence. The facts that the early flood salt current often undercut, like a wedge, the diluted water in the upper channel, and that the upland water occasionally flowed down over the top of it, might account for any further apparent discrepancy in the actual early time of low-water, to which the continued downward flow seemed to be a visible contradiction. The mean rate of rise of the ordinary spring flood-tide in the Orwell, and at Ipswich, was 1 foot in thirty-two minutes, and of the ebb 1 foot in twenty-three minutes; but the latter was increased after two-thirds ebb to 1 foot in twenty minutes until nearly low-water, and operated, it was believed, in scouring away from the last and lowermost 1½ mile of channel the deposit of silt which took place upon the flood, the bed of the channel being generally gravel and coarse sand. In Harwich Harbour the rates of rise and fall of the tide were practically the same as above stated for Ipswich. He submitted that the above

Mr. Miller. remarks fully bore out the conclusions drawn under head 3 of the Author's summarized views, as expressed in clauses *a*, *b*, *c*, *d*, *e*; and as to clause *g*, though not bearing directly on the case, it was undoubtedly an advantage to the estuary of the Orwell to be fed with tidal water having momentum in a proper direction at its mouth, which was set up and maintained by a larger and nearly independent body of water, and the converse seemed equally applicable. As to head 1, its truth in the case of Harwich Harbour was self-evident before the commencement of the Conservancy Board's works, the material forming the shoal across the harbour entrance, which would have operated as a bar, consisting entirely of littoral sand and shingle swept, by wave-action, along the beach, the direction of which being north-east, was in the line of strong gales and greatest extent of open and rough sea. As to head 2, by the operation of the Harbour Conservancy Board's works, upon which he had acted as Assistant Engineer, a greater freedom for the influx and efflux of tidal water had been secured, and though the actual capacity of the estuaries had not been materially increased, the direction of both flood and ebb at the entrance were so much improved by training, as to have resulted in an earlier high-water at Ipswich, and lower ebb both in the harbour and the Orwell, than had been the case for many years, previous to the execution of those works.

Mr. Shield. Mr. W. Shield, of Peterhead, from personal observation of the movement of sand bars at the mouths of rivers and estuaries, and the changes which they underwent, had been led to the conclusion that, in the great majority of cases, wave-action was the principal force instrumental in their formation. Shore currents were, for the most part, only felt, to any appreciable extent, at salient points of the coast; and the so-called littoral currents, along receding shores, were generally only the "set" caused by waves impinging on the shore at an acute angle, or variable surface currents caused by wind. Their direction and intensity, therefore, varied with the wind, as did also, other things being equal, the direction and amount of littoral drift. The tendency of waves meeting a river-current obliquely was to gradually force it over towards the shore. This seemed to be due to the combined effect of the waves upon the flank of the current, the run set up along the shore by the waves, and their ceaseless endeavour to form a continuous line of beach past river mouths or estuaries, in defiance of the ingoing and outgoing currents, as the Author had pointed out. In extreme cases, when the preponderance of power was largely on the side of the waves, as, for instance, when the tidal currents, into and out, from the river were feeble, or when strong winds blew for long periods from the same quarter, the river-current was often pushed so far over that its direction approached to parallelism with the shore; indeed, he had known instances in South Africa during dry seasons, where the enfeebled river-current, having been diverted in the manner indicated, had lost so much of its remaining energy, by percolation through its newly-formed seaward bank, that the waves had succeeded in blocking up its mouth altogether. Under such circumstances a lagoon had been formed, a portion of the water brought down by the river continuing to find vent by percolation. When this happened, or even in less extreme cases, when the river-channel had not been blocked or diverted to the full extent named, the river-current, especially if assisted by a freshet, usually broke through the bar, forming a new channel for itself, almost in its normal direction; and the battle between it and the waves recommenced. Where the direction of the winds was variable, the movement of the channel would, as a matter of course, be irregular. The treatment of bars must vary in each individual case, according to the physical conditions affecting them; but, in most cases, the protection of the river-current from the wave-stroke until it reached deep water would, he thought, be found an important feature. As regarded the contracting of harbour entrances, for the purpose of increasing the scour upon bars, it ought to be borne in mind, in deciding the extent to which this should be done, that the removal of a bar had for its special object the convenience and safety of shipping. It would not, therefore, be desirable, in removing one evil to create another, by unduly increasing the velocity of the ebb current in the hope, it might be, of saving some small expenditure in dredging; because, when such a current encountered storm waves, a dangerous sea resulted, and vessels endeavouring to fetch the harbour during a gale, with but little canvas set, were liable to lose way, become unmanageable, and, missing the entrance, go on shore. The history of many wrecks in past years at the mouth of the Tyne and elsewhere would, he thought, support this view. In these days of steam this difficulty was, no doubt, less serious than it used to be; nevertheless, the time did not seem to have arrived yet when the requirements of sailing vessels, and especially those of the large fleets engaged in the fisheries, could be overlooked. Mr. Shield.

Mr. W. SMITH, of Aberdeen, was glad that the most important, if not the sole, cause of the formation of bars across the mouths of estuaries in comparatively deep water had been specified by the Author on p. 122, namely, the action of waves driven along, which Mr. Smith.

Mr. Smith. presumably included on the shore, in piling up detritus in the direction of their greatest force. At Aberdeen Harbour a bar consisting of the beach of boulder-clay was removed from the entrance channel by dredging from thirty to twenty years ago. Although this bar consisted of hard material, it formed again repeatedly as often as dredged away by the piling up of fine heavy sea sand driven in by the waves during storms. For years it appeared impracticable to secure a permanent increase of depth of water by dredging on the bar; the depth gained by dredging during the summer was silted up again by storms in the following winter. The tidal and river-currents had no effect upon the sand at the greatest height of the bar, when the depth at low-water was only 8 feet. During the last five years a considerable permanent improvement had been observed; much less sand was driven in from the sea during storms, and soundings in the bay immediately outside the harbour entrance indicated the existence of a hollow or deepening in continuation of the line of the entrance channel, for 2,000 feet outwards till it reached a depth of 30 feet at low-water. Thus by continual re-dredging, until the supply of sand overlying the boulder-clay immediately outside the entrance was exhausted by wave-scour, a permanent improvement of depth, or rather diminution of the rate of silting, had been obtained. The Author appeared, however, to classify littoral currents with waves, p. 136, in which he was joined by Mr. Vernon-Harcourt, quoted on the same page, in carrying forward material and forming bars. In Aberdeen Bay two rows of banks and lagoons extended from Aberdeen Harbour northward 15 miles, the tail of the southernmost outer bank forming the bar. There it might be observed at low-water that the littoral currents were produced by the waves falling over the banks and entrapped within the lagoons, seeking outlets between the banks. Instead of forming banks or carrying sand on shore, the littoral currents invariably kept open the passages by which the back-water of the waves escaped from the lagoons out to sea. A constant circulation of sea-water was thus kept up in the bay during storms, the water rolling over the banks in waves and escaping from the lagoons back to sea as littoral currents. Dublin Bar and Tees Bay, the only successful examples of deepening by scour induced by artificial works, appeared to owe their success to this principle of the generation of an outward littoral current, by entrapping waves, added to the ebb-tide current. At Dublin, the North Bull formed an artificial submerged bank 1½ mile long, the whole of the waves falling over which were entrapped, and the water could only escape as a powerful littoral under-current through the harbour entrance immediately over the bar. The bar being formed by waves, the outward scouring action of the littoral under-current was greatest when most required to meet the action of storm waves. At the Tees, the building up of the Gares into breakwaters, excluding the waves and stopping the generation of outward littoral currents, would probably be followed by additional silting on the bar. The tidal currents had no effect at Aberdeen in keeping the harbour or bar clear of silt, and never had at any period of its history. The supposed effects of ebb-tide currents, guided by artificial works, should be more clearly proved from observation before the profession went to sleep over the theory. Millions of money had been thrown away upon this time-honoured fallacy; the improvement of the River Tyne was delayed by it many years, and the estuary of the Mersey was still kept a hopeless puddle with an unimproved bar. The scour by ebb-tide currents maintained an estuary in a state of nature, but failed to improve it; artificial works should aim at the application of additional forces. The movement of sand under water by wave-scour was subject to the following laws:—1. The scouring power of a wave increased with the size of the particles of sand up to a maximum size of grain, depending upon the dynamic head of the wave. (The limit for great waves might be stones of several tons weight.) 2. The weight of unit sand-cube movable by a wave, varied, directly as the sixth power of the velocity equivalent to the dynamic head of wave and the cube of the depth, and inversely as the square of the mass and the cube of the internal friction of the mass or skin friction of its particles. 3. The sorting of sand into various sizes of grains, the largest being driven highest up on the beach and deposited on the steepest grade, and the smallest grains remaining at the level of low-water at a slope nearly horizontal, was due to the variation of the resistance by internal friction of the mass when rolled on shore by the waves. Mr. Smith.

Let m = constant of mass of sand.
f = coefficient of friction.
q = viscosity or frictional adhesion of water to surface of materials.
a = length of sand cube.
$h = \frac{v^2}{2g}$ = dynamic head of wave.
w = unit of weight of water.
d = depth from crest to trough of wave.

Mr. Smith. Then for equilibrium

$$f \cdot m \cdot a^3 = q\left(w \cdot d + w \cdot \frac{v^2}{2\,g}\right) 6\,a^2,$$

therefore
$$m\,a^3 = \frac{\left\{6\,w \cdot q\left(d + \frac{v^2}{2\,g}\right)\right\}^3}{f^3\,m^2}, \text{ second law,}$$

and
$$\frac{f \cdot m}{q \cdot \left(w \cdot\ d + w\,\frac{v^2}{2\,g}\right) 6\,a^2} = \frac{6\,a^2}{a^3}.$$

Let $q\left(w\,d + w\,\frac{v^2}{2\,g}\right) 6\,a^2 = p =$ scouring power of wave, and make p constant and a variable; then the frictional resistance of the mass of sand $f \cdot m$ varied inversely as the length of side or size of the unit grain (first and third laws), which was observable on all beaches where the materials of the sea bottom varied in size. This was evident in the formation of the Chesil Bank and a similar bank of stones recently formed at the mouth of the River Findhorn, and was practically demonstrated every winter at the back of Aberdeen South Breakwater and in many similar positions.

Mr. Stevenson. Mr. C. A. STEVENSON remarked that the Author had given a very distinct account of the origin and formation of bars, especially maintaining the value of back-water theories, which had been first advanced by Mr. David Stevenson in communications to the Royal Society of Edinburgh, and stated more in detail in his work on "Canal and River Engineering." The Author seemed to neglect the relative value of tidal water at different levels, which was a most important question. *Fig. 1*, showing a line of embankment running up both sides of the estuary, was rather misleading, for in most estuaries if this rough and round system of encroachment were adopted, by carrying walls far up the river as shown, there would result in most cases a diminution of the water in the channel, and eventually a decrease of water on the bar. Possibly A A A might be excluded with benefit to the bar, but the lines of encroachment did not stop here, but proceeded up the river. The work on the right bank of the river, also, could not be advantageously proceeded with, unless the level of the high-water was exceptionally low, or some compensating quantity of tidal water were admitted by works, as the water so excluded had a direct influence in maintaining the channel and bar. It was unnecessary to detail all the calculations to be made in such encroachment, as they had been explained in the latest edition of Mr. Stevenson's

"Canal and River Engineering," where most of the problems to be solved were fully treated. Mr. Stevenson.

Mr. Stoney. Mr. BINDON B. STONEY observed that most of the bars round the coasts of Great Britain and Ireland were due to the sea endeavouring to continue the coast-line across the mouth of the river, including in the term river not merely that portion which lay between high banks, as defined by the Author, but also the channel which extended at low-water from the bar inland. In this sense an ordinary bar was the limit of the river seawards. While the river, together with any tidal water which flowed and ebbed over the bar, strove to maintain the passage free and open, the sea tended to close it, and according as one or other of these antagonistic forces prevailed, so would the bar improve or the reverse. When they balanced, the bar remained in a fairly permanent condition, especially if the depth at low-water over its deeper portion was greater than that at which wave-action was sensible in that locality. The measures most successful in removing bars such as those now referred to might be broadly divided into two classes, represented by the works at the mouth of the Liffey and those at the mouth of the Tyne. In the former case a large volume of tidal water, which formerly wasted its strength over a wide surface whereby its scouring effect was thinned out, was concentrated and directed on the bar, which was outside the piers. In the case of the Tyne, piers had been extended into deep water a considerable distance beyond the coast-line, and the bar was dredged away in the calm water inside. As it no longer formed a continuation of the coast-line, the cause of its formation was cut off, and being under similar conditions, it practically formed a portion of the river-channel inside the piers and no longer presented the characteristics of a coast-bar. It would be observed that these two methods of treating bars were widely different. In the Liffey, the scour of a large volume of tidal water was concentrated on the bar, which was outside the piers. In the Tyne, piers were run out into deep water beyond the bar, and the latter was then dredged away. When a large volume of tidal water was concentrated so as to scour a bar, the deepening of the channel inside was beneficial; but its effect was moderate compared with that of the concentrated scour. Its benefit, as regarded a bar, was twofold. First, it enabled tidal water to flow higher and further up the river and estuary, and thus increased the volume of back-water. Secondly, if the borders of the river channel through the estuary were not embarrassed by training-walls extending as high as the strands which skirted the channel, a large quantity of sand would each

Mr. Stoney. year be washed off these strands into the channel and would be dredged away in the maintenance and improvement of the channel. This shedding down of the strand would, in the course of years, have a great effect in lowering the strands of the estuary above low-water, especially where steamers passed up and down frequently, and this action would enlarge the tidal capacity inside the bar. In the earlier designs for the Manchester Ship-Canal, this consideration had not as much weight as it was entitled to, and there could be little doubt that, if the canal had been made through the estuary with training-walls considerably below the level of the sands, a great deal of material would have been gradually washed off the strands into the channel and dredged away annually in its maintenance, and the level of the sands for long distances on each side of the deep channel would in time have been greatly lowered. An expenditure of £10,000 a year in dredging maintenance (a moderate sum for such a great work), would in a very few years have removed as much sand as the great fret was said to have brought down, and much more annually than ordinary frets; and the tidal capacity of the estuary above Liverpool would have been enlarged, in place of being diminished, by the construction and maintenance of a canal with low training-walls. The Author seemed to think that the scouring effect on a bar of the flood-tides and ebb-tides was nearly balanced. This was certainly not the case in the Liffey, where the flood-tide came into the river from the south, in place of over the bar, which was about 1 mile outside and east of the entrance between the piers. The flood-tide entered and flowed round the bay by the south side, and so up the river between Poolbeg Lighthouse and the bar. The Author also seemed to think that cutting off indents of estuaries, and thus reducing their tidal area, might be carried out without detriment to a bar; but though doing so might have no prejudicial effect in cases where the scour was not concentrated, it should not be forgotten that, if hereafter artificial means were adopted for concentrating the scour, the reclamation of large portions of the estuary inside might have a prejudicial effect, by reducing the volume of the scouring water, and it could not be too clearly kept in view that volume as well as velocity was necessary for the removal of great masses of sand such as existed on most bars.

Mr. Thorowgood. Mr. F. N. Thorowgood stated that, in the construction of the harbour at Madras, two very interesting cases of sand movement were exhibited, which although not applying directly to bars of tidal estuaries, nevertheless might be mentioned in connection with the Paper under discussion. The first case was quoted to

Mr. Thorowgood.

show the action of waves upon the sea bottom in moderate weather, under certain conditions; and again, how in heavy weather the action was different. The Author mentioned how ridges of material forming bars, exposed to storms and waves of the open sea, were sometimes partly dispersed; but that they reverted to their former forms when the disturbing cause had ceased. It was an instance of this action which he wished to refer to. When the north pier of the Madras harbour had reached a depth of water of between 3 and 4 fathoms, the rubble base on which it was founded being about 3 to 4 feet above the natural sea bottom, in one single night the upper surface of the rubble base was completely buried in fine sand for a depth of 3 feet. When this obstacle first appeared, there was no sensible current up or down the coast in a depth of 2 fathoms; the sea was quiet, excepting for the perpetual swell off the Coromandel coast, and the south-west monsoon had not set in. For a whole month (April) this sand, with variations of depth, continued to cover the base, to the great delay of progress. In May the Bay of Bengal was visited by a violent cyclone, which raised for thirty hours a very confused and heavy sea. On examining the base, after the sea had subsided, it was found that the sand was completely washed away. On attempting to resume work, however, the next day, the sand was found to have returned as badly as ever. Surveys taken at the time showed that it was a local heap tapering off to seaward, and varying from 3 feet to 7 feet in depth on the top of the rubble. It was important to note that there was no perceptible littoral current nor oblique action of the waves when this sand first appeared. It remained as an obstruction for many months, and the pier of concrete blocks was with difficulty advanced through it; but when the 5-fathom depth was once passed, the sand returned no more. In the following year (1878) the south pier of the harbour (parallel to the north and 3,000 feet south of it) went through precisely the same difficulty. He found from records of soundings at Madras, ten and twelve years previous to 1877–79, that there had frequently been a movement towards shore, from 4½ fathoms inwards, of sand on the sea bottom, causing great inconvenience to boats plying at the iron screw-pile pier at Madras. Surveying in the swell over these sandbanks was so difficult and dangerous that he was not able to give a statement of tons of material with accuracy; but probably the mass of sand which moved so capriciously was about 2,000 tons. He could have no doubt, from twelve years' experience of the currents and waves on the Coromandel coast, that in the case of both piers the obstructing and shifting sand was moved by

Mr. Thorowgood. wave-action inwards from deeper water, and deposited where a solid and new obstruction caused a local eddy. The second case to which he would refer pointed out an example of what the Author described as "waves driven along the shore, piling up detritus in the direction of their greatest force." At Madras, as the south pier was projected into the sea, during every south-west monsoon (from about April to September) the waves, striking the sandy coast with a slightly oblique advance from south to north, brought with them an immense and alarming quantity of sand, which was stopped by the solid wall of the south pier, and thereby caused a gradual and certain advance of the shore-line. This sand would naturally have passed up the coast northward; but, being arrested, its absence soon was plainly felt to the north of the harbour, where the waves attacked the coast in a similar direction, cutting into the shore-line and carrying away villages, temples and plantations; and as no material came from the south to compensate for erosion to the north, a regular system set in, and now continued, of accumulation to the south, and of erosion to the north. In the first eighteen months of construction the shore had advanced permanently a distance of 540 feet alongside the south pier, and in 1888 the permanent advance of sand was about 1,200 feet. At a distance of ¾ mile and 4 miles southward respectively from the south pier were two rivers, and during the period of accumulation of sand the mouths of these two rivers were hopelessly blocked up with sand, scarcely any water being able to penetrate to the sea, showing that the enormous quantity of wave-borne sand passed over the mouths of unimportant rivers.

Mr. Turner. Mr. J. H. T. Turner desired to take exception to the Author's statement that, "The scouring power of the water is a compound force depending on velocity and weight." He would venture to point out that this was not in accordance with the generally accepted laws of fluid friction; nor was it reconcilable with the expressions commonly used in hydraulic calculations.[1] The fact

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[1] Take, for example, the ordinary form of equation for steady flow in an open channel—

$$v = c\sqrt{R \cdot i},$$

which might be written

$$i = \frac{v^2}{c^2 R},$$

i.e.

$$(\text{surface slope}) = \frac{(\text{velocity})^2}{\text{constant} \times (\text{hydraulic mean depth})}.$$

There was no term here indicating pressure or weight, as an element of the calculation. The surface slope in the channel, which measured the frictional resistance to the flow—in other words, the scouring power of the water—was seen to be, for similar channels, whatever their actual depth, simply dependent upon the velocity.

that scour depended in a very high degree upon the velocity, and not at all upon the weight or pressure of the water, had an important bearing upon the Author's second conclusion. A better scouring effect might result from the latter portion of the ebb, though small in volume, impinging with considerable velocity upon a bar when the water was low. For the scouring energy was then less deadened by encountering a large mass of inert sea-water, and was therefore more fully utilized in washing away the bar. So far as estuaries were concerned, it was widely recognized that many of them owed their continued existence to the erosive action of low-water channels, which cut down the banks, and thus neutralized the predominating influence of the flood-tide. But, with respect to a bar, which indicated a balance of landward and seaward forces at its site, the case was different. It was not easy to see that, in all cases, training-works could cause the ebb-tide to issue over the bar with a higher velocity than that of the flood-tide, to whose original energy it must always owe its motion. But a predominating influence might be given to the ebb-tide, by causing its flushing action to act vigorously upon the bar during the latter part of the ebb, in the same manner as a dock entrance was most effectively sluiced at low-water. If the entire volume of the flood could be stored in an estuary, as in a flushing-tank, until near the time of low-water, and then discharged upon the bar, the greatest scouring effect would be gained. This was impracticable; but, by improving the channel, as the Author recommended, so as to carry high-water far inland, the latter part of the ebb-current was actually strengthened, when the depth of inert water on the bar was comparatively small, and the velocity and consequent scouring effect of the ebb were least checked thereby. In this sense it was possible to give, by skilful rectification of the channel, the "greater preponderance to the ebb-current" desired by the Author. He concurred in the opinion expressed in the Paper, that, by such means, an "improvement in the outfall channels of estuaries might generally be effected;" but he doubted whether the "dispersal of bars" was always likely to follow as a natural consequence. Where the presence of a bar was due to the action of on-shore waves heaping up a barrier of gravel or sand, the dispersal of the bar by such means might not mean more than its removal a little farther seaward, to a point where the scouring force of the improved current was dissipated in the open sea. Mr. Turner.

Mr. G. van Diesen agreed for the most part with the conclusions of the Author drawn from the facts which he had collected; but he desired to make the following observations on some points in Mr. van Diesen.

Mr. van Diesen. connection with them:—"1. That the causes which operate in maintaining the existence of bars in tidal estuaries come from the sea, and are not due to the inland water." The rivers which carried sand did so by scouring at the narrower parts of their channels during freshets. Generally they transported the particles of sand by rolling them on the bottom; but, in any case, the sand carried down was river-sand, and the water that moved it was river-water. If the mouth seawards widened so much that the velocity of the river-water became too small to carry the sand further, then it remained and formed a shoal or bar which encumbered the navigation; this especially took place when the slope of the channel seawards at the enlarged part of the mouth was small. In these circumstances, the motion of the sea-water could have no influence on the formation of the shoal. Although this was shown unquestionably by the formation of bars or shallows in river-mouths, where no tide existed, or almost none, yet it was also proved in Holland by the sudden deposit of a sandbank in consequence of the scouring of the too narrow channel of the New Rotterdam waterway, when the "Scheur," the former river-mouth, was dammed off. This sandbank, known as the "West Bank," which stopped the mouth of the river, had, by narrowing the mouth and by dredging, been entirely removed, so that now a depth of 75 decimetres (24½ feet) existed, where in 1882 there were only 35 decimetres (11½ feet). The shoal outside the mouth of the Yssel in the Zuiderzee furnished an instance of deposit at a point where the river-water had almost lost its velocity in the sea. In making the above observations he only desired to show that rivers could form bars without the help of the sea. It would appear from the Author's remarks on the Danube and the Mississippi that these rivers were also in the same position.

"2. That the dispersal of bars, and the improvement of the outfall channels of estuaries, can be accomplished by increasing the volume and velocity of the tidal water passing over the bar, and by giving a greater preponderance to the ebb current." The increase of the velocity of the ebb as a means of insuring the preponderance of the scouring power of the ebb-stream, by increasing the volume of outgoing water, must be sought rather by giving to the river seawards a less width than that proportional to the quantity of water passing through. In some cases even a narrowing of the mouth might be necessary, as had been done with good results at the Danube, the Mississippi, the Liffey, the Tyne, and the Tees, and as had been caused in the Humber by natural means. At the Yssel, the narrowing of the principal mouth had been united with a reduction in the number of mouths. If the engineer, with the idea of admitting a large quantity of flood-water, made the mouth too wide, he incurred the danger of the formation of two or more outflow channels, none of which might possess sufficient depth. The Tees, before its improvement, was an example of this. Sufficient flood-water could be admitted for the tidal movements, and for the preservation of the depth of the river through a narrow mouth, provided it had depth enough, of which the Tyne, the Tees, and the Liffey were cases in point. Mr. van Diesen.

"3. That in designing works for this purpose the circumstances of those estuaries which have natural deep-water channels free from bars should be taken as guides."

"(*a*) That the mouth of the outfall should be capacious enough to allow of the entry of sufficient tidal water to fill up all the estuary and upper reaches of the river." With this principle he agreed entirely.

"(*b*) That to ensure a regular and undisturbed flow the form of the estuary should be such as to afford a gradually decreasing width from the outfall." The width of most rivers, with or without bars, diminished upwards with greater or less rapidity, and such diminution was generally regarded as desirable; but the rate of such diminution did not appear to be universally admitted, which arose from the fact that the engineer had to deal with an undefined hydraulic problem, of which the solution was dependent on a knowledge of the just requirements which ought to be satisfied. It was quite possible, and even probable, that a river might maintain sufficient depth at the mouth, although there was no reduction in the width for a considerable distance inwards, or even the opposite might be the case. The Scheldt and the Tagus furnished instances of this. Every reduction of watershed capacity diminished the quantity of flood-water which helped to preserve the depth of the mouth. In the case of the Thames, the range of the tide had been greatly increased by the enlargements of the channel effected at London Bridge and elsewhere in London. Hence he could only agree with paragraph (*b*), if it was meant that the junction of the wide mouth with the narrower channel inside should be gradual, and not if it was implied that the narrowing within was necessary.

"(*c*) That the depth of water in the channel should be sufficient to allow of a free propagation of the tidal wave." To this he fully assented. Sufficient breadth as well as sufficient depth must be secured by dredging, in order to allow the flood-water to run up as far as possible.

"(*d*) That the longer the run of tidal water that can be given

Mr. van Diesen. the more effective will be the scouring action, and that therefore all obstructions to the free flow of the tidal current are prejudicial to the outfall." He entirely agreed with the opinion that the admission of the tidal water as far up as possible was conducive to depth at the mouth, and he had supported it under (*c*) above.

"(*e*) That it is essential to secure adequate depth of the channel by natural scour or by dredging." In this too he fully concurred.

"(*f*) That training and fixing in one position the low-water channel in a sandy estuary is of first importance in securing the full advantage of the tidal scour, and in maintaining a deep channel." A channel must be made by cutting off bends, and be preserved by training-works as much as possible in the situation and direction which might be found suitable.

"(*g*) That water flowing in and out of an estuary which does not pass to or from the sea over the bar, and by the main navigable channel, is of no advantage to the outfall, and is better excluded; therefore, while it is of the utmost importance to conserve an estuary as a receptacle for the tidal water, the exclusion of such water from indents, and the cutting off of irregularities by embankments, may be carried out without detriment to the outfall." As stated in discussing clause (*b*) he considered a regular form of channel for the flood stream very desirable. However, to avoid useless currents, he thought a decided funnel-formed channel, enlarging seawards, was ill adapted for scouring away a bar: in his judgment an opposite form, as in the case of the Liffey, was required.

"4. That piers carried out from the shore are useless unless extended to deep water. That they should be so designed as, while not unduly throttling the inflow of the tidal water, they should effect the greatest amount of scouring force from the ebb current." The depth to which the piers should be extended was dependent on the width to which their heads must limit the mouth of the channel, that was to the depth to which the inflowing and outflowing water might be counted on to scour and maintain the channel between the heads of the piers. The channel would extend itself to a certain distance outside the mouth, and if this took place to the desired depth in the sea, then it would not be necessary to extend the piers to that depth.[1] The channel of the New Rotterdam waterway had between the piers a depth of 75 decimetres (24½ feet) below low-water, and reached that contour line in the sea at a distance of 750 metres (820 yards) outside the

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[1] Projet des travaux à faire à l'embouchure de la Seine, par L. Partiot.

piers, which, however, only extended to a contour line of 50 decimetres (16½ feet). In the case of harbours, it was necessary to carry out the piers to the desired depth; but these did not form part of the subject of the Paper. Mr. van Diesen.

Mr. JOHN J. WEBSTER remarked that, while he agreed to a great extent with the conclusions arrived at by the Author, he took exception to several statements in the Paper. In the first place, the Author stated that, "If the quantity of tidal water be diminished, the channels will deteriorate;" this, however, was not supported by facts; for it was quite possible to reduce the amount of tidal water flowing into an estuary, and at the same time improve the navigation by increasing the depth at the bar. If the estuary was of large extent, and encumbered by sandbanks, well-designed works of reclamation would direct the water, which flowed uselessly over the banks, into well-defined channels; and although the amount of water which formerly entered the river might be greater than that which flowed subsequent to the reclamation works, the depth, and velocity of the flow, would be considerably greater. In many estuaries, the quantity of water which now flowed would be more than sufficient, if properly directed, to scour out any obstruction at the mouth; it was, therefore, possible to exclude tidal water and improve the channels. Of course, if the works were badly designed, the results would be disastrous—a notable instance being the works on the River Dee, near Chester, mentioned by the Author. The original object of those works was reclamation pure and simple; not with the object of improving the estuary, but of obtaining land. If, however, the scheme of Telford had been carried out in its entirety, and the wall, locally known as the causeway, extended further out to sea, forming a trumpet-shaped low-water channel, as designed by Telford, a deep-water channel would no doubt have been maintained from Chester to the sea. Whatever works were undertaken in a broad sandy estuary, for improving the channel, must of necessity be of a permanent character; dredging operations alone would only possibly give temporary relief. Taking the case of the estuary of the Mersey, which was a typical illustration in many ways, any attempts to dredge away the bar could not possibly meet with success; for a single gale might sweep away the works of months, and a costly fleet of dredgers, which would be in the way of the shipping, would have to be constantly maintained. The Mersey was a notable instance of how reclamation works, properly designed, would enable Nature to maintain a constant deep-water channel or channels. The physical difficulties were not great, and Mr. Webster.

Mr. Webster. the cost would not be so great as was generally supposed; for by gently assisting Nature, by permanent works and dredging, not only would well-defined, deep channels be formed, sufficient for any possible or river traffic, but thousands of acres of the Burbo and other banks would be reclaimed, the value of which would far exceed the amount expended upon the works. In speaking of the question of bars being formed by detritus carried by the ebb, the Author stated that the material brought down the river consisted of matter which was too light to remain on the bar, and was carried to sea. Further on, however, he stated that heavy land-floods had been followed by a decrease in the depth of water at the bar, and as an instance, quoted the great "fret" in the Mersey, which diminished the depth at low-water from 11 feet to 7 feet. The statements did not quite agree; and, from the fact of the increase in the depth at the bar to its average condition subsequently taking place, it would appear that the detritus could be deposited on the bar, but not to form a permanent obstruction. The Author held an entirely different opinion from that of the late Mr. W. R. Browne, as to the effect of fresh water on bars, and stated definitely that fresh water alone was not competent to keep the outfall channel clear from a bar. He then quoted, as an illustration, the case of the Mississippi. If it was not the fresh water alone, confined by the well-designed works of the late Captain Eads, which had cleared away the obstruction at the mouth, increasing the depth from a few feet to 30 or 40 feet, to what other agency was it due? The Author also stated that: "When the estuary is small, as compared with the magnitude of the river" . . . "land-floods may increase the depth over the bar." That the effect was more apparent under these conditions might be admitted; but that the action was still existing with the conditions reversed, must also be admitted, although the effect might not be apparent. The Author stated that if any portion of an estuary was filled with fresh water, it excluded an equal amount of tidal water, and that, with few exceptions, the level of high-water in a tidal estuary remained unaltered during the heaviest floods. This could hardly be true, either theoretically or practically, for, in the first place, the momentum of the flowing tide would push back a quantity of fresh water which might have entered the estuary; again, the rising tide flowed underneath the fresh water, raised it, and backed it up until an equilibrium was maintained. After the equilibrium, came the practical proof of both the tidal and flood water being in the estuary, in the form of flooded fields, towns, and villages. When the tide ebbed, the floods immediately followed it, and must increase

Mr. Webster. the amount of water flowing over the bar at the ebb. Whether the estuary was large or small, the same action took place, although the apparent effects might be different. It was this backing up of the flood-water by the advancing tide which acted as a natural dam; and when this dam receded, the powerful effects of released impounded land-waters were developed. The Author accounted for the non-existence of bars, at the mouths of several estuaries, from the fact of there being a promontory or projection of the coast-line, which caused the tide to run round it with considerable velocity, producing great scour and deep water. That the projection might act as a groyne, and arrest the progress of the sand or shingle washed along the coast by the wind-waves, might be admitted; but the washing round the corner, with consequent scour and deep water, was not so apparent, and the illustration of the Humber was not a happy one. There was undoubtedly a projection at the mouth, Spurn Point; and there was no bar; but this was due chiefly to the form of the estuary—its great length, breadth, slow current, and the exceedingly light nature of the material held in suspension, the particles passing up and down the estuary with the tides, slowly depositing within the estuary, and forming the well-known banks of mud.

Mr. Wheeler. Mr. W. H. **Wheeler**, in reply to Mr. Dyce Cay, could not agree with him that any advantage would arise from the diversion of river water from an estuary, even if it were possible. The work which the fresh water stream did in keeping the upper part of a river at the head of the tide free from deposit, as previously pointed out, made it of the greatest value. If this deposit were allowed to accumulate, the river would gradually silt up, the length of tidal run, and consequently the quantity of tidal water passing over the bar, would be diminished, and so one of the most valuable aids in maintaining a deep channel over the bar be lost. Mr. Griffiths challenged the conclusion he had arrived at, that in designing works for the improvement of bars, the circumstances of those estuaries which had natural deep-water channels free from bars should be taken as guides, and instanced the piers in the Liffey, as, although not conforming to this idea, had yet been successful in deepening the water over the bar; but he further stated that great caution should be exercised by others in adopting similar works. From the remarks subsequently made by Mr. Mann, this caution appeared to be well founded, as he stated that "since 1880 there had been no increase in the depth (over the bar), but, he believed, rather the contrary." From this it would appear that, although the concentration of the water on the bar by the converging

Mr. Wheeler. walls, and the creation of a powerful scouring agent over a small area, had exercised a beneficial effect in making a deeper channel, this result showed signs, as time went on, of not being permanent. It would seem that the scour caused by converging walls of this class was too local. The bar had been removed from the immediate vicinity of the pier-heads, but had formed again further out, and the water might probably, in process of time, become as shoal as before. It therefore yet remained to be seen whether a more permanent result would not have been obtained if the advice of Captain Bligh and the Tidal Harbour Commissioners had been followed, and a form given to the works which would have brought the shape of the estuary more in accordance with those natural outfalls which have no bars. The very strength of the stream, caused by the form of the contracted entrance, was liable to create an amount of disturbance which might be the cause of evils as great as the bar itself; and, by unduly throttling the tide, and increasing the area of the harbour inside, prevent the tidal water from reaching to the same extent up the estuary and river which it otherwise would do. The outfall would thus be deprived of the scour due to water which would pass out towards the end of the ebb, and the river also deprived of a valuable scouring agency. It was undesirable to create a greater velocity than was absolutely necessary to give the ebb sufficient force to keep down the bar. The passage of a large volume of water concentrated through a comparatively narrow opening might be as injurious to the navigation as the bar itself, and make the entrance through the pier-heads difficult and dangerous for vessels entering or leaving when the flood or ebb currents began to attain their full flow. He quite acknowledged that, under the circumstances mentioned by Mr. Messent, a bar would be a great disadvantage to the navigation, although not actually diminishing the navigable depth of the channel. In making the statement, he only intended to show that bars were not always the shoalest part of the channel. He wished, however, to point out that, unless some protection from cliffs or artificial piers existed, a deep pool inside a bar on a flat coast was no safer place for a vessel to ride than in the offing outside the bar. The instance quoted by Mr. Messent of the Ribble was a case in point. Vessels waiting to make this channel did not lie at anchor in the pool immediately inside the bar, but at a safe distance outside the bar. He was glad to be able to have the opportunity of recording his testimony as to the value of the magnificent works which were being carried out under Mr. Messent's direction for the improvement of the Tyne,

Mr. Wheeler. and the very successful results which had followed—results which were sufficient fully to justify the design. He had never intended to convey the idea that these designs were due to the writing or theory of Captain Calver, but only that they were in accord with certain principles which Captain Calver had expressed. There was nothing in the evidence of Captain Calver, given before the Commission on Harbours of Refuge, quoted by Mr. Messent contrary to these views. The opinion he expressed before the Commissioners was that, as the piers extended seawards, sand would be liable, in the process of years, to gather round the ends and shoal the water, this period depending on the amount of tidal water admitted into the enlarged harbour on the one hand, and the supply of coast-drift on the other. As a broad principle, it could not be contended that Captain Calver was wrong in this. The piers had been carried out a long way into deep water; an enormous amount of sand, which formerly had accumulated on the coast, had been removed by dredging. Up to the present time, and no doubt for many years to come, the supply of drift along the coast would not be sufficient to allow of any accumulation, and there was every reason to suppose that, even when this took place, the great scouring power of the increased volume of tidal water acquired by the works would be able to cope with it. But, in process of time, as the littoral drift operated in bringing fresh supplies of sand, it was not improbable that the coast-line would extend seaward, and the travel of the material being stopped by the pier acting as a groyne, sand would once more accumulate at the outer extremity, and try to form a bar. To what extent it would succeed would depend, as Captain Calver said, on the amount of tidal water admitted into the harbour by the works. If this was sufficient to make the ebb current strong enough to master the sand thrown across the ends of the piers, as no doubt it would be, deep water would be maintained; but, if not, shoaling would result. The Tyne works, as distinguished from those of the Liffey, were designed to propagate the tidal wave to its fullest extent, and give the longest practicable run to the tidal water, and were therefore more likely to be permament in their results. Mr. Webster objected to one of the conclusions at which he had arrived, namely, that if the quantity of tidal water in an estuary be diminished, the channel would deteriorate, and pointed out the circumstances under which, in his opinion, such water could be diverted without detriment to the bar. In doing this he had, however, omitted to take notice of the qualification to this conclusion as explained by *Fig. 1*, and in paragraph (*g*), p. 143. In fact, Mr.

Mr. Wheeler. Webster only corroborated the opinion he had expressed in the Paper. Mr. Webster also called attention to what he considered a discrepancy between the statements in the Paper:—(1) That the material brought down the rivers in freshets was not of the same character as that of which bars were formed, and (2) that the fretting of the sands in the upper estuary of the Mersey did add to the material on the bar. He failed, however, to notice the distinction between the accumulated sand in the estuary and the detritus brought down by the rivers. The material of which the estuary consisted was pure sand, and of similar character to that found on the bar, and was entirely different to the alluvial matter brought down in suspension by the Irwell and the Mersey. He could not agree with Mr. Webster that the tidal water acted as a natural dam in penning back the fresh water. A dam implied the actual stoppage of the water, whereas the great advantage of a tidal stream was that nothing of this kind took place, but that the water was always alive, except for the short period of high-water slack, when the direction of the current was being reversed.

On the whole, the written communications were strong testimonies to the soundness of the conclusions arrived at in the Paper. While repudiating the idea set forth by Mr. Griffith, that they were ever intended as "an infallible guide for the treatment of bars," he claimed that the Paper, with the discussion, would be of service to students in considering one of the most difficult subjects which an engineer had to deal with.

11 February, 1890.

SIR JOHN COODE, K.C.M.G., President,
in the Chair.

The discussion, on the Paper by Mr. W. H. Wheeler on "Bars at the Mouths of Tidal Estuaries," occupied the whole evening.

18 February, 1890.

SIR JOHN COODE, K.C.M.G., President,
in the Chair.

(*Paper No. 2386.*)

"Shanghai Water-Works."

By JOHN WILLIAM HART, M. Inst. C.E.

I. INTRODUCTORY AND STATISTICAL.

THE Shanghai Water-Works were the first water-works constructed either in China or in Japan, and as there are no particulars available for reference regarding this class of works in the far East, nor respecting the cost of labour and materials for their construction, it is hoped that this Paper may supply some facts worthy of record.

Shanghai, Plate 6, the chief commercial centre in North China, taking into account its importance on that account and large population, may be regarded as the Metropolis of the Far East. It consists of foreign settlements, enjoying certain municipal rights secured by treaty, and of a native city inhabited solely by Chinese and by a few European and American Missionaries. It is situated on the River "Hwang-Poo" about 14 miles from the Woosung Bar, at the entrance to the river. It is approached from the sea for some miles through the estuary of the great "Yang-Tsze-Kiang," the source whence the "Hwang-Poo" derives its chief supply. The range of the summer spring-tides is from 8 to 9 feet, and the current flows at 4 miles an hour. The country is flat, of alluvial formation; the nearest highland or eminence is fully 20 miles distant from the river.

The port was opened to foreign trade by treaty with Great Britain in the year 1843, and the site for the English settlement was then selected. However, all treaty nationals have an equal right to locate themselves there, and to become possessed of land and other property in accordance with the terms and stipulations contained in the treaty. The boundaries of the English settlement are well defined, but the area is far too limited for the rapidly-increasing trade and population of the port.

The river is on the east side of the settlement, and upon its margin there has been constructed a magnificent road and promenade ("Bund"), also a public garden overlooked by palatial buildings, which would do credit to any city in Europe. The Defence Creek is the westerly limit of the settlement, and the Soochow and Yang-King-Pang Creeks are the northern and southern boundaries, with the Bubbling Well Road extending westward to the suburbs beyond the settlement.

The American settlement called "Hong-Kew" is a continuation of the English settlement, and extends along the bank of the river for about 3 miles in a northerly direction. The settlements are separated by the Soochow Creek. The French settlement, small and very irregular in form, has a frontage of about ⅓ mile. It is separated from the English settlement by the Yang-King-Pang Creek, and extends in a southerly direction to the walls of the native city. About 1865 the English and American settlements were amalgamated, and from that date one municipal council, composed of nine members (not Chinese), elected exclusively by the foreign ratepayers and property owners of all nationalities, has administered the affairs of the settlement. The French have their own municipal council of eight elected members, four French and four of other nationalities (not Chinese). The French Consul is an ex-officio member of this body, and he has power to dissolve the council or to veto any resolution it may pass. The absence of facilities for appealing against the arbitrary and special power possessed by the Consul operates against the advancement of the settlement, and to this and other flaws in its municipal government may in some degree be attributed the fact that the growth and success of the French settlement has not been so marked and satisfactory as that of the Anglo-American or "sister settlements." Indeed, the French settlement, with its independent municipal council, would seem almost an anomaly, considering its limited population and other circumstances. It has been computed that over 60 per cent. of all the property in the French settlement is owned by subjects of other nationalities, and a great part of the remaining 40 per cent. is held by the Roman Catholic missionaries and other French subjects not engaged in commerce. The amalgamation of the three foreign settlements under one municipality would be of inestimable value to the European and American community of Shanghai.

In the three settlements, subjects of the treaty powers may acquire land in perpetuity, but liable to a nominal ground rent payable to the Chinese authorities. The ordinary municipal taxes are devoted exclusively to the maintenance of the police, lighting, and to sanitary and other public purposes within the area of the settlements.

The public roads and principal thoroughfares in the Anglo-American settlement and suburbs measure about 48 to 50 miles in length, and in the French settlement there are 12 to 14 miles of streets. The settlements are connected by bridges crossing the various creeks, and these bridges are free of toll.

In 1881 the Chamber of Commerce at Shanghai compiled a statement showing that at that time fully £15,000,000 sterling was invested in land and other property in the foreign settlements, and it is estimated that the total capital invested at the present time cannot be less than £20,000,000 sterling.

The statistics compiled by the Maritime Customs show that the total value of the imports and exports for the year 1887 exceeded £34,500,000 sterling, approximately 70 per cent. of the whole being the British proportion of the trade. The shipping in and out of port in 1887 was 5,474 vessels, having a gross carrying capacity of 4,827,185 tons, and of this total tonnage 53 per cent. was British.

In 1875 there were in the Anglo-American settlements 13,892 dwelling-houses, and in the French settlement, 6,260, making a total of 20,152 dwelling-houses of all classes, exclusive of warehouses, manufacturing premises, and other special buildings. In 1885 the number of dwelling-houses in the Anglo-American settlement was 21,500, and it was estimated that in the French settlement there were about 8,000, making a total of 29,500, or an increase in ten years of 54·76 per cent. in the Anglo-American settlements, and of 27·79 per cent. in the French settlement. This increase took place chiefly within the latter half of the period mentioned.

The population of the settlements has grown with equal rapidity. In 1875 the Anglo-American settlements had a population of 97,338, 95,662 natives and 1,676 foreigners; and the population of the French settlement was 33,300 natives and 300 foreigners, giving a total of 130,938 in the three foreign settlements. The census for 1885 showed that there were 129,338 inhabitants in the Anglo-American settlements, while the estimated population of the French settlement in that year was about 40,000. Thus the total population of the three settlements was about 169,338, and in ten years the population of the Anglo-American settlements increased 32·87 per cent., and that of the French settlement 19 per cent. These figures exclude seamen employed on board ship in port and the native boat-population. If these were included it is estimated that the figures quoted would be increased by about 7½ to 10 per cent.

The Chinese city is surrounded by high walls with four entrance gates, which are guarded day and night and are closed after sunset. Its population has been variously estimated at from 100,000 to 150,000.

For twenty years previous to the commencement of the works, which it is the purpose of this Paper to describe, the necessity for an efficient water service was fully realized by the municipality and the community, and the matter was brought under their notice on several occasions by the Author of this Paper and by others. Mr. Thomas Hawksley, Past-President, was instructed by the municipality to report on the merits of the alternative schemes submitted by the late municipal engineer for his consideration, but his report, like others, was followed by no practical results. In 1880 the Author of this Paper was again invited to investigate the question, and to prepare plans and estimates, and these, under the auspices of several influential Shanghai merchants, were submitted to the municipality with an application for a concession to construct the works. This application was granted almost unanimously by a fully-attended meeting of ratepayers.

II. WATER-TOWER AND TANK, PLATE 7, FIGS. 1 AND 2.

The advantages of a constant- over an intermittent-supply of water had, of course, to be taken into account in the proposed scheme, and it was of special importance to provide a reserve in case of an outbreak of fire. Serious conflagrations had occurred in Shanghai from time to time, and, as the condition of the tide and other causes had interfered with the working of the fire-engines, great destruction of property had followed. There were, however, grave obstacles in the way of providing such a reserve. The nearest high land suitable for a storage reservoir is fully 20 miles from Shanghai, and quite inaccessible. A site could not have been obtained from the Chinese authorities if desired. Moreover, there were obvious objections to laying the supply-main beyond the jurisdiction of the municipality. To obviate these difficulties the Author decided to construct, in a central position within the English settlement, a water-tower, which should contain a reserve of 150,000 gallons at an elevation of 103 feet 6 inches from the centre of the main to top-water level.

The resolve to adopt this alternative was not undertaken without realizing the difficulties to be encountered in securing a good foundation on ground composed of alluvial deposit, and notoriously bad for supporting structures of this class and weight. The Author's experience and observation in the construction of works in Shanghai had led him to conclusions adverse to the practice—which was the general rule followed until a recent date—of using piles for foundations in such places. In Shanghai excavations cannot be carried to more than a few feet deep without water filling the trenches; and, in short, the ground is in the worst condition for receiving a large number of piles driven in close proximity to one another. By such an operation the mud is wrought into a spongy and semi-liquid state, in which condition it is less capable of sustaining heavy weights than when undisturbed. For these and other reasons, no piles were used in the foundation of the water-tower, or in any other part of the works, and the result was a considerable saving of time and expense.

The original intention was to carry the foundation to a greater depth than that adopted. But the difficulties experienced in keeping the trench clear of water, and the danger to private property in close proximity, resulted in trial experiments to ascertain the sustaining capabilities of the ground at a depth of 12 feet below the surface. For testing the ground, a slab of strong Portland cement concrete, 12 inches thick with an area of 13½ square feet, was made in the centre of the trench. On the concrete slab a timber platform was placed, care being taken to adjust this platform so as to guard against inequality of pressure when the test-weights were applied.

Pigs of lead were laid on the platform progressively at different dates, and levels were taken on each occasion. No attempt was made, during the trial, to keep the trench dry. The ground was thoroughly saturated with water, and it was therefore in a condition unfavourable to the sustaining of heavy weights. The following Table shows the results of the experiments:—

AREA OF TESTING-BLOCK OR SLAB 13·5 SQUARE FEET.

Number of Tests.	Total Weight on Testing-Block.	Total Weight per Square Foot Area.	Number of Days before adding Additional Weight.	Subsidence due to Additional Weight.	Total Subsidence.
	Lbs.	Lbs.		Inch.	Inches.
First	17,500	1,296·29	4	..	⅜
Second	30,625	2,268·52	6	1⅛	1½
Third	35,000	2,592·59	8	½	2
Fourth	51,100	3,789·00	18	1¼	3¼

The maximum final test-load of 3,789 lbs. per square foot area of foundation, as noted in the foregoing Table, was allowed to remain for eighteen days. More weights were then applied, but no perceptible depression was caused. This led to the conclusion that the ground could be loaded with safety to the extent of 3,789 lbs. per square foot. The dimensions of the concrete foundation for the tower are 68½ by 65 feet = 4,452½ square feet area, and the total weight to be supported is as follows:—

Summary of Weights.

		Tons.	Tons.
Rough rubble and concrete	=	1,833	
Brickwork in Portland cement	=	772	
Masonry	=	130	
			2,735
Ironwork and materials in superstructure	=		320
Weight of water in the tank, 150,000 gallons	=		670
			3,725

The figures in the foregoing Table show that it was necessary to make provision for supporting a maximum permanent load of 3,725 tons, or 1,847 lbs. per square foot area of the foundation. It will be observed that this is only a little more than 51·25 per cent. of the load applied in testing the ground, and that consequently there is ample margin for safety. There was no hesitation, therefore, in proceeding to construct the foundation without the use of piles.

When the ground had been tested in the manner described, it was found necessary to suspend the work for a short time in consequence of the severity of the winter. In the interval, in a shed adjacent to the trench, preparations were made for measuring and mixing the materials required for the foundation, and three of Huxham and Brown's concrete-mixing machines, and a portable engine for working them, were erected.

When the work was resumed, the materials were measured in boxes made to the sizes corresponding with the proportions to be used. The materials were first mixed nearly dry by hand on a large platform immediately below the mixing machines, and were then passed to the machines in baskets. Here they were thoroughly mixed and continuously discharged automatically from the machines. The concrete was then carried away in baskets by coolies and laid in the trench, where it was carefully and well rammed with wooden malls.

The proportions of materials used for concrete were as follow:—

PROPORTIONS for CONCRETE.

Portland cement	in parts	1
Native lime	„	1
Well-washed sand	„	1
Gravel and small granite chips . . .	„	2
Granite, 2-inch cubes	„	4
		9

The concrete foundation is 5 feet thick and founded upon 2 feet 6 inches of rough rubble thrown into the trenches, and was deposited in five separate layers each 1 foot thick. Each layer was commenced at the side of the trench opposite to that at which the preceding layer was begun, and by this alternation the layers were made to overlap each other, and thereby the risk of faults and defects was reduced to a minimum. On the average, nine days were allowed to elapse between the laying of each layer, and twenty days after the completion of the last layer of concrete, brickwork for the foundation was commenced. The bricks obtainable in Shanghai are of inferior quality. In this case, though specially made and extra burnt, and though every care was taken to procure the best that could be obtained in the locality, they were much inferior to those used in England for similar purposes. Large blocks of granite are procurable only at a considerable distance from Shanghai, and at extravagant prices. For these reasons the pier-blocks for the columns and the coping-stones were imported from Hong-Kong. The weight of each of the top pier-blocks is 4½ tons.

All the brick and masonry work is set in Portland cement, in proportions of 1 part cement to 1½ part fine sharp sand. Including an interval in which the work was interrupted by frosty weather, a period of six months was consumed in laying the concrete and constructing the foundation. As the work progressed, levels were taken at frequent and regular intervals; and when completed, it was found that the steady accumulative weight of materials used (2,735 tons) had caused an even settlement of 2¼ inches.

The superstructure for supporting the tank (Plate 7, Fig. 1) is exclusively of iron; octagonal in form, 52 feet 6 inches in diameter from centre to centre of the columns. There are twenty-four columns erected in three tiers of eight each. They are 26 feet long from face to face of the flanges. The sole-plates for the columns are 3 feet 6 inches square and bed direct on the granite piers built in the brickwork. The sole-plate for supporting the centre tube is cast in one piece, with apertures and suitable flanges for the reception of inlet, outlet, and overflow pipes. It weighs 5½ tons.

The column sole-plates are connected with and bolted to the centre tube sole-plate by cast-iron radial girders bedded on to the coping-stones of the radial walls of the foundation. These walls radiate from the sole-plate for the centre tube to each pier.

The sole-plates and the radial girders are secured in position by 1½ inch foundation bolts built into the brickwork and piers. By connecting the sole-plates of each of the columns with the sole-plate of the centre tube by means of the radial girders in the manner described, the whole weight to be supported is evenly distributed over the surface of the foundation, and the risk of the columns spreading or of inequality of pressure in case of settlement is in this manner reduced to a minimum.

The centre tube is 6 feet in diameter, 82 feet 6 inches long, made of boiler-plate ⅜ inch thick. At the base a strong angle flange-plate riveted to the tube is bolted to a corresponding flange cast on the sole-plate, and a perfectly water-tight joint is thus made. At the top end of the tube there is a similar flange-plate, to which are riveted the floor-plates of the tank. Eight vertical stiffening ribs of T iron, bedded into the lower and upper flange-plates, are riveted to the side of the tube, which thus forms a rigid central column, and does duty with the outer columns in supporting the tank and the water therein.

It also serves the purpose of an ordinary stand-pipe, when it is found desirable to work with a varying head of water. This can be done during the greater part of the day, without reducing the pressure below what is necessary to meet the usual requirements of the highest building in the settlement.

To ensure the greatest rigidity, the columns of each tier are connected at the capitals with tie-girders made in halves, and bolted together in the centre, the ends being fastened to raised flanges cast on each column.

Over the centre connecting-joint of the girders an ornamental shield is placed in the form of a keystone, to screen the flanges and bolts. Radial tie-girders of light wrought-iron lattice-work connect the centre tube and the columns, one end of the girders being bolted to the capitals of each of the columns in the same manner as the ornamental girders which connect the columns of each tier, while the other end is provided with a gusset-plate riveted to the T vertical stiffening ribs of the centre tube. The diagonal bracing consists of screw tie-rods 1½ inch in diameter in every bay between the columns, and radially in every bay between the columns and the centre tube. There is an ornamental centre box for receiving the screw ends of the tie-rods; and by means of screw-nuts inside the box each rod is tightened and adjusted.

The top or floor girders for supporting the tank and water are of steel of the lattice type. The outer ends rest direct on the column flanges to which they are bolted, and to ensure even settlement there is a sheet of lead ⅜ inch thick between the bed-plate of the girders and the flange of each of the columns. The inner ends of the girders next the centre tube have strong gusset-plates with cheek angle-irons, firmly riveted to the vertical stiffening bars of T iron and to the sides of the centre tube, so that the whole weight to be supported is transmitted between the outer cast-iron columns and the centre tube. In addition to the eight principal steel floor-girders, they are also connected with intermediate girders, the whole forming a suitable platform to receive the hard-wood joists upon which the floor of the tank rests.

The tank is 50 feet diameter by 12 feet 3 inches deep, and contains 670 tons of water. It is made of boiler-plate, the floor plates being ⅜ inch thick, and the side plates from ⅜ inch to $\frac{5}{16}$ inch thick. The floor-plates are riveted to and connected with the upper flange of the centre tube, and are bedded on hard-wood joists, resting on the steel floor-girders. The tank is stayed inside with stiffening bars of T iron riveted to the side and floor-plates, to which are secured diagonal gusset stay-plates. There are also screw stay-bolts from the side plates of the tank to the centre column which supports the roof.

The roof is of light construction, the principal and intermediate rafters are of angle-bars, one end being riveted to the side plates of the tank, while the other is bolted to a flange-plate on the top of the centre column. This column rises from the floor-plates and supports the roof, bolted between another set of flanges of the centre column. There is a wrought-iron plate, and to this plate are fastened struts, which radiate at equal distances for stiffening and supporting the rafters. The roof is covered with corrugated galvanized iron, and closely resembles the construction of an ordinary umbrella when open.

Round the tank there is a gallery 6 feet wide, supported by light cantilevers fastened to the ends of the steel floor-girders. To screen the water from the sun, the gallery roof is pitched to an acute angle.

To approach the top and intermediate galleries from the foundation, there is a set of spiral steps fastened to the centre tube, and there are landings at the level of each tier of columns. These facilities for inspection place the tank and the whole superstructure at all times under immediate view, and render them accessible for painting and repairs.

Though only one 20-inch pumping-main has been laid between the water-tower and the pumping-station (Plate 7, Fig. 2), more than 3 miles lower down the river, the necessary provision has been made for a duplicate main to be laid when required. The mains are connected with the tower by a breeches-pipe, which is bolted to the flange of the inlet-aperture cast on the sole-plate of the centre tube. The inlet-aperture is 28½ inches in diameter, and has a bell-mouth discharge-pipe, which rises 10 feet inside the centre tube. The two outer branches of the breeches-pipe for the pumping-main are, of course, 20 inches diameter; they have flanges for the reception of sluice-valves, so that one or both may be opened or closed, and thus one or both of the pumping-mains may be used at the same time as circumstances require. There is a reflux-valve between each sluice-valve and the mains. When the main pumping-engines are working, these valves allow free ingress to the water delivered from the pumping-station, but when the engines are at rest, the pressure of the head of water in the tank and centre tube closes the reflux-valve, and thus stops the egress of the water except through the proper outlet passage.

The outlet-aperture is cast on the sole-plate of the centre tube in the same way as the inlet-aperture, and over the outlet, inside the centre tube, there is a large strainer, through which the water must pass before leaving the tower. Thence the water flows through a nest of triplicate 12-inch meters, placed immediately between the outlet and the supply-main leading to the settlements. Each meter is provided with separate strainers and sluice-valves, through which the water passes before entering the meters. Only two of the meters are used at one time, and are changed at set intervals. To provide against the risk of flooding the tank by over-pumping, there is, inside the centre tube, an overflow pipe, 20 inches in diameter, with a large bell-mouth at full-water level. The overflow water escapes through the aperture in the sole-plate of the centre tube, and is discharged into a well with a division-wall to break the fall, and then runs to waste through the public drains.

The water leaving the tower through the meters is registered every day at noon, and compared with the quantity delivered from the pumping-station. Any discrepancy, of course, indicates leakage somewhere between the pumping-station and the water-tower.

Immediately in front of the water-tower there is a 20-inch by-pass main connecting the inlet and outlet branches of the pumping- and service-mains, and should the tower be under repair, the main pumping-engines, which are provided with exceptionally large air-vessels, can deliver the water direct through all the settlements. To effect this, it is only necessary to open the sluice-valve on the by-pass main, and to close the sluice-valves on the inlet and outlet branches leading to and from the tower. The total height of the water-tower from the roadway to the crest of the terminal on the roof is 121 feet.

The work of erecting and lifting the parts of the superstructure into position was carried out with great rapidity and dexterity by Chinese riggers, who are adepts at lifting heavy weights, and who, under skilled direction, excel in tasks of the kind required of them in this instance. The appliances used in performing the work were of the simplest and most inexpensive description. Timber spars were spliced together to form a derrick of sufficient length to lift the top tier of the columns and other heavy parts into position. The spar was stepped into a timber frame, in the centre of which was cut out a step or cup-seat for the spar to rest in. To prevent the spar from shifting, it was held in position by timbers wedged to the walls of the foundation. The top end of the derrick-spar was secured and moved into position for the different lifts by ordinary guy-chains, which were lengthened or shortened by means of blocks. To the head of the derricks two sets of large blocks were secured for lifting the parts, one set being worked with a winch and the other with a capstan. The sole-plate for the centre tube was the first lifted into position; the sole-plates for the columns followed, and then the radial cast-iron girders for connecting the column sole-plates with the centre tube sole-plate.

After the first tier of columns and the first length of the centre tube had been erected, and when the bracing-girders and diagonal tie-rods were in position, all the parts were accurately adjusted, and each sole-plate was brought to a true level by means of steel wedges. This done, the spaces between the piers, the coping-stones, the sole-plates, and the radial girders were grouted with Portland cement, and when the cement had set and become hard, the steel adjusting wedges under the sole-plates were drawn or cut off, and the foundation-bolts were firmly screwed down. The succeeding tiers of columns were erected in a similar manner. All joints are machine-faced and screwed firmly together, metal to metal, with turned bolts inserted in holes made to fit them exactly. The plates for the tank, and the separate lengths of the centre tube, were sent up in pieces and temporarily fastened together with screws, bolts and nuts, and afterwards riveted in position. Levels were taken when each succeeding tier was completed, and again when the whole superstructure was finished, and it was found that the settlement due to the increased weight of the superstructure (320 tons) was imperceptible.

While the water-tower was in progress, the pumping-engines and boilers were erected, and when the 20-inch main between the pumping-station and the tower was completed, the engines were started to pump water into the tower, and thus further test the stability of the foundation.

The water was pumped at set intervals until the tank was filled. Levels were taken from time to time, and at the expiration of the number of days noted below, the settlement due to the increased weight was accurately recorded, and the results were tabulated as follow :—

WEIGHT of WATER PUMPED into the TOWER.

Number of Test.	Weight of Water pumped into the Tower.	Days before adding Additional Weight.	Total Weight of Water in the Tower.	Remarks.
	Tons.		Tons.	
First	54	5	..	The test-loads given in this Table had no perceptible effect on the foundation, and no settlement could be detected, though levels were taken with the greatest care.
Second	176	5	230	
Third	124	7	354	
Fourth	95	4	449	
Fifth	63	8	512	
Sixth	70	10	582	
Seventh	88	12	670	

The figures and data show that, from the commencement of the foundation to the final tests, the total subsidence amounted to 2½ inches, due to the gradually increasing weight of the foundation, superstructure, and water. When the tank is full the total weight to be supported is 3,725 tons. For more than three years levels were taken frequently, but not the slightest change in the permanent set was detected.

The following sums represent the total cost of the water-tower, exclusive of land.

	£.
Cost of superstructure, including meters, reflux and other valves and accessories, with freight and insurance . .	5,378
Cost of foundation, earthwork, brickwork, and masonry .	4,371
„ erecting superstructure and riveting tank . . .	2,100
	£11,849

The tower has been subject to severe strains by several typhoons, and not a single defect has been discovered. Except as regards the cost of painting and cleaning, the cost of maintenance has been nil.

III. Pumping-Station and Filter-Beds.

The Yang-Tsze-Poo works and pumping-station, Plate 7, Fig. 3, are on the bank of the River Hwang-Poo, below the shipping and harbour limits, but within the area of the Anglo-American settlements, and therefore within the control of the municipality. The site is more than 3 miles from the water-tower, which has been erected in a central position in the English settlement. The total area of the land acquired for the works is nearly 18½ acres, and this is more than sufficient for the present works and future extension. A surplus of over 5 acres is available for other purposes.

There was a diversity of opinion regarding the most suitable site for the intake and works, and the supposed advantages of other sources of supply were brought under the notice of the public. Some persons favoured what is known as the "Lung-Wha" scheme. The site, which would have been occupied by the works if this scheme had been adopted, is on the river above the shipping, foreign settlements, and native city, but it is beyond the boundary and jurisdiction of the municipality. Others wished that the water should be taken from the Soochow Creek, or the Yang-Tsze-Poo creek; and bolder projects, which had the disadvantage of being utterly impracticable, were advocated. The Author was guided in his selection of the "Yang-Tsze-Poo" site chiefly for the following reasons.

At the "Lung-Wha" site the sectional area of the river is comparatively small, and the volume of water much less than that available at Yang-Tsze-Poo. The impurities from the drains of the foreign settlements, the creeks, native city, and shipping are carried by the inflowing water to the upper reaches at Lung-Wha, and consequently at flood-tide the water would not be in a desirable state of purity to be passed through the intake well to the settling-reservoirs. Similar objections would apply to the admission of the water on ebb-tide, owing to local and up-country contamination of the river. But the gravest objection to the Lung-Wha scheme is that the supply-main for the greater part of its length would be outside the foreign settlements and the jurisdiction of the Anglo-American municipality, and could only be laid by permission of the Chinese authorities, which would lead to difficulties almost insuperable.

The volume of water in the Soochow Creek and in the Yang-Tsze-Poo Creek is small, and there is a very large boat and junk traffic, and a considerable floating population. Moreover, the up-country drainage and the Chinese method of fertilizing the low lands on the banks of the creeks, are not conducive to the purity of the water. For these reasons it seemed obviously objectionable to take the supply from either of the creeks.

The Yang-Tsze-Poo site has the advantage of being down the river, below the native city, foreign settlements, and shipping, and at the intake well the risk of the contamination of the water from these sources or from the creeks is almost if not entirely avoided, in a manner which will presently be explained. It is to be observed, too, that the sectional area of the river at the intake is greater than elsewhere within the harbour limits, and the importance of having the Company's property within the jurisdiction of the Anglo-American municipality, and outside the control of the Chinese and French authorities, was a weighty argument with the Author in determining the selection of the site.

By the flood-tide the sewage from the settlements and native city, and the impurities which find their way into the river from the shipping and from the creeks are carried into the upper reaches in the direction of Lung-Wha. The valves of the intake-well are so placed, that when opened they cannot admit water until fully one hour after the flood-tide has set in, therefore the water enters the settling-reservoirs nearly at the top of flood-tide, when it is in its purest state. It may be added that the result has fully justified the selection of this site.

The river is always in a turbid condition, especially in summer, and the partial purification of the water by subsidence is absolutely necessary before filtration can take place. At no time is the water sufficiently free from argillaceous substances to be passed from the river direct to the filters, and though exposure in the settling-reservoirs has its advantages in assisting to precipitate the heavier particles held in suspension, it is desirable that the water should not remain exposed to the action of the sun longer than is absolutely necessary. The formation of fungus on the surface of water thus exposed in the climate of Shanghai is very rapid, particularly in the summer, and filtration as soon as possible is therefore most desirable.

Plate 7, Fig. 3 represents the general arrangements of the pumping-station and Yang-Tsze-Poo works. The river and side embankments are raised 3 feet above high-water mark, to guard against the risk of inundation in high winds and typhoons. The embankments are 12 feet wide on the top, and have an inner slope of 3 in 1, and on the outer or river side, a slope of 1 in 6. The whole is trimmed and covered with turf, and the outer slope to high-water mark, and for some distance on the foreshore, is thickly planted with fast-growing shrubs, which spread at the roots, and protect the banks from the scour of the tides, and from the wash of large steamers.

There are two settling-reservoirs, with an exposed water surface of 75,000 square feet collectively. Each reservoir is 250 by 150 by 13½ feet deep, with a total capacity of 6,130,312 gallons, and arrangements have been made for a third reservoir, when such is required, designed to hold 2,762,500 gallons. The reservoirs are on the foreshore of the river, with the floor or bottom 4 feet below low-water mark, and the coping of the retaining-walls 6 inches above high-water mark, to prevent the possibility of over-filling or flooding.

Concrete was the only material used in the construction of the settling-reservoirs. The retaining-walls are founded on 18 inches of rubble, and the floor on 12 inches.

The walls have an inside batter of 1 in 6, with buttresses 18 feet from centre to centre. The walls are 3 feet 3 inches thick at the footings, and 2 feet at the coping.

The footing courses were built in rough timber moulds of the required width and depth. These moulds were placed in position, and the concrete was formed in one continuous slab for the entire circumference of the reservoir, and was consolidated with timber malls.

For the construction of the walls, timber guide-piles were driven into the ground at suitable distances in two rows, and were securely stayed at the required batter of 1 in 6. Planks were fastened to the guide-timbers so as to form a mould 2 feet deep for the reception of the concrete. Four gangs of coolies were employed to carry the concrete in hand-baskets from the machines to the moulds. The first two gangs laid the material 12 inches deep, half the thickness, and worked in reverse directions, until they met at a point of the circumference of the mould opposite that at which they commenced. Two other gangs of coolies followed at a distance of about 100 feet, and laid the next layer in the same way. In this manner the finishing point of each layer was overlapped by the preceding layer, and throughout the whole wall from start to finish, no two layers terminated at the same point; but at a considerable distance apart. As the work progressed, the concrete was rammed and well consolidated with wooden malls. After allowing the necessary time for the concrete to set, the moulds were removed and placed in position for the next 2 feet in height, and so on until the wall was finished. This method of working combined economy in the first cost of timber, with facilities for rapid construction.

The floors of the reservoirs consist of 12 inches of rubble covered with 12 inches of concrete. For the easy discharge of the sediment, the floor has an inclination to the centre transversely of 1 in 150, and longitudinally of 1 in 250; both the walls and floor are rendered in strong Portland cement.

The intake-well is placed in the river 25 feet beyond low-water mark. It is a cast-iron cylinder, 6 feet in diameter, made in 6 feet lengths, with machine-faced flanges inside. When the lengths were bolted together, the well was sunk into the bed of the river, and afterwards filled with cement concrete to within 2 feet of the inlet-valves.

These valves are bolted inside the cylinder, and they have strainers outside. They are 2 feet above low-water mark, and thus any risk of the water entering the reservoir at the commencement of flood-tide is obviated. From the embankment the intake-well is approached by a gangway bridge, 136 feet 6 inches long, in three spans, 45 feet 6 inches each.

On the well-gallery, at a level with the gangway bridge, there are columns for receiving the valve-spindles and wheels for opening and closing the river-valves.

The supply-main for conducting the water from the intake-well to the reservoirs is 30 inches in diameter, and 260 feet long. It is laid through the embankment and middle space between the end retaining-walls of the reservoirs, and on the inshore end it has a blank flange to provide for extensions, if the construction of another reservoir should become necessary. To relieve concussion in case of the rapid opening of the river intake-valves, a large air-escape pipe is carried up from the main to the surface. Two cross-connecting branches are placed on the 30-inch main with two 22-inch supply-pipes, and sluice-valves to each reservoir, and by this arrangement one or other of the reservoirs may be filled or used alternately, independently of each other. A reflux-valve is also placed on the 30-inch main, and this, while allowing the water free ingress to the reservoir, closes automatically should the attendant neglect to shut the river-valves at the proper time, and prevents the egress of the water with the ebbing-tide.

In each reservoir, there is a floating outlet-pipe for supplying the auxiliary engines for the intermediate lift between the reservoirs and the service-tanks for the filters. Each of these pipes is 18 inches in diameter, and 20 feet long, and the lower end is seated in and connected to a cast-iron saddle-box made with a movable water-tight joint. The saddle-box is secured to the retaining-wall, and to foundation stones, which are built in a tray sunk 3 feet 6 inches below the floor-level of the reservoir. The other end of the outlet-pipe is fitted with a rose-mouthed strainer pierced with small holes, and is floated by a buoy 6 inches below the surface of the water. Obviously, the water, when taken from the reservoir in this manner, is obtained in its best condition. The discharge is regulated by sluice-valves, the spindles of which pass through a guard-pipe to the surface, and then through columns 3 feet high.

The proportions used for concrete are given in the annexed Table. The material was measured and mixed in the manner described in the remarks on the water-tower foundation.

PROPORTIONS for CONCRETE.

Portland cement	in parts	1½
Native lime	,,	1½
Well-washed sand	,,	2
Gravel and small granite chips . .	,,	4
Granite, 2-inch cubes	,,	6
		15

The following Table shows the approximate total quantities. It also shows the total cost of constructing the reservoirs, exclusive of the cost of land, and that the cost was £1,804 per million gallons capacity.

ABSTRACT of QUANTITIES, and TOTAL COST of SETTLING-RESERVOIRS.

			£.
Earthwork, excavations, and forming river- and side-embankments . . .	cubic yards	84,000	1,465
Rough rubble	,,	4,722	7,052
Concrete, for retaining walls, floors, &c.	,,	6,841	
Masonry, coping and sundry stone-work,	cubic feet	3,200	
Ironwork, including freight, insurance, and charges . . .			1,200
Erecting intake-well, supply-mains, &c., including gangway bridges			561
Damage by typhoons, and other special charges			780
			£11,058

The cost of earthwork is comparatively high, owing to the treacherous nature of the soil. In fine weather the ground presented no special difficulties; but after rain it was impossible to define any angle of repose. Frequent slips, and considerable delay and expense, which would not have been incurred under more favourable circumstances, were the results.

The service-tank for feeding the filter-beds is 220 feet by 92 feet by 8 feet 6 inches deep, and contains 996,000 gallons of water. It is built on made ground, raised 3 feet 6 inches above the surface or road-level. The walls are of brick, and are built to a batter of 1 in 6, in bays 18 feet 6 inches from centre to centre of the buttresses. They are 2 feet 6 inches thick at the footings, and 1 foot 9 inches thick at the coping. The floor of the tank is formed of 12 inches of concrete laid on 12 inches of rough rubble, and the surface is rendered with cement. The tank is divided into three compartments by two stiffening or division walls, and there are, between each compartment, communicating or equalizing valves. By this arrangement, the sediment can be flushed out of any one of the compartments while the others are in use.

Two advantages were gained by constructing a tank of such large capacity instead of passing the water direct to the filters.

1st. The tank does duty as a subsidiary settling-reservoir, and further assists in removing, before the water is passed to the filter-beds, the earthy matter held in suspension.

2nd. It contains a supply sufficient to feed the filters during the night, so that it is not necessary to resort to the aid of the auxiliary centrifugal engines after the ordinary working hours.

There are four filter-beds, with provision for constructing four more. They have a total surface of 4,266·5 square yards, and each bed is designed to filter 30,000 gallons of water per hour. They are all 120 feet by 80 feet by 9 feet 6 inches deep, with 5 feet 6 inches of filtering materials. The walls, which are of brick set in Portland cement, are well backed with puddle. They are 3 feet thick at the footings, 2 feet 6 inches at the coping-stones, and are built to a batter of 1 in 12. The floor is of concrete 12 inches thick, laid on 12 inches of rubble. The surfaces of both the walls and the floors are rendered with Portland cement. For the purpose of avoiding the difficulties of excavating, and for economizing the cost of construction, the walls are raised 3 feet above the surface or road-level. The water percolating the filtering materials is drawn off through twelve rows of 8-inch earthenware pipes laid 10 feet apart. It is then discharged into a central culvert communicating with the outlet-well, which has a sluice-valve to regulate the rate of percolation. The 8-inch pipes are laid with open joints, and from each row there is an air-pipe leading to the surface. In other respects, the only particular in which the construction of the filter-beds differs from the ordinary plan is in the application of a special supply-valve instead of the ordinary sluice-valve for feeding the filters with water. The Chinese cannot be trusted to regulate the supply-valves so as to prevent the water running to waste, and to ensure a uniform head of water on the filtering materials. To obviate the risk of a varying supply, each filter is furnished with a double-seated balance-valve, worked automatically by the rise and fall of the water on the filtering materials. One end of the valve-lever is inserted in a joint on the valve-spindle, and the other is affixed to a float placed in a well 2 feet in diameter. Each of the wells is supplied with water through a pipe which is built into the wall of the filter, and which leads from the filter; and the float is adjusted to suit the condition of the filtering materials, and the depth of water to be kept on the filter-bed. Thus waste is prevented, and a settled head of water, which may be varied at pleasure, is ensured. The average rate of percolation has been 540 gallons of water per square yard per twenty-four hours, and the average duty of each filter before it required cleansing was equal to nearly 9,000,000 gallons of water filtered.

The clear-water or service-reservoir has a capacity of 840,000 gallons. It is 120 feet by 80 feet by 14 feet deep to full-water level.

The retaining-walls are of brick set in Portland cement, having a batter of 1 in 6, with bays 19 feet from centre to centre of the buttresses. On the top of the buttresses bedding-stones are set to receive the cast-iron girders from which the roof-arches spring. The walls are 3 feet thick at the footings, stepped and reduced to 2 feet at the coping-stones. The floor is formed of 18 inches of concrete on 18 inches of rubble, well rammed with wooden malls, and afterwards rendered in Portland cement. It has an inclination to the tray or sump for the exit valve to the outlet well of 1 in 120. The roof is formed of six arches in 19-feet spans one brick in thickness. The ends of each arch are left open for ventilation. The haunch spaces between the arches are filled with concrete, upon which 3-inch pipes with open joints are placed for drainage. The roof is covered with 18 inches of earth on the crown of the arches, the whole surface being spread with fine turf.

The clear-water culvert from the filter-beds discharges into the reservoir inlet-well, which is 6 feet in diameter. By opening or closing one or other of the valves in the inlet well, the water from the filter-beds can be allowed to escape through a by-pass culvert to the pumping-well direct, or through a 21-inch by-pass pipe, which connects the inlet and outlet-wells. Thus provision is made for diverting the water from the filter to the main pumping-well direct, and for shutting off the reservoir should it become necessary to clean or repair it. The outlet-valve is placed inside the reservoir in a tray or sump 2 feet 6 inches below floor-level, and it is well protected with strainers. The water is discharged into the outlet-well, which is also 6 feet in diameter, and thence it flows through a 21-inch main to the pumping-well constructed under the verandah of the engine-house.

The main building (Plate 7, Figs. 4) is 180 feet long by 61 feet wide and 20 feet high, from the surface-level to the top of the coping. It is subdivided by party-walls, and contains the engine-house, the valve- and gauge-room, and an office. Under the same roof are the boiler-house, coal store, general store and workshop, with a store-room and office. The engine-house has a clear floor without any obstruction, and is 63 feet by 45 feet. The roof is supported by light ornamental elliptical girders in one span.

In consequence of the faulty character of the ground, it was found necessary to build the chimney-shaft for the main boilers immediately in front of the main building. The foundation is a block of concrete 20 feet by 20 feet by 4 feet. The reason for adopting a foundation of this class without the use of piles, has been fully stated in the remarks in this Paper respecting the water-tower, and the difficulties of constructing in Shanghai a foundation to support heavy weights. The chimney is 91 feet 6 inches high, from surface-level to the coping, and 103 feet to the crest of the iron terminal. It is lined with firebrick for 15 feet from the base, and its internal diameter is 6 feet 9 inches at the base, and 5 feet at the top.

The total weight on the foundation is 571 tons, which is equal to 1·427 ton, or 3,201·5 lbs., per square foot.

There are two sets of horizontal compound pumping-engines, one set of the rotative type, and the other of Davey's differential class. Each of these engines is designed to deliver into the water-tower 75,000 gallons per hour. The engines are supplied with steam by three Cornish boilers 26 feet long and 6 feet in diameter, each with two furnaces and Galloway tubes. Ample space has been provided for additional and larger engines and boilers when required.

Two sets of duplicate centrifugal pumping-engines raise the water from the settling-reservoirs to the high-level service-tank, which acts as a subsidiary settling-reservoir and feeds the filter-beds. The water, on leaving the outlet-pipe from the settling-reservoirs, passes through a brick culvert, 2 feet 6 inches in diameter, to a pumping-well 23 feet 3 inches deep in the main engine-house. Over this well there are two centrifugal pumping-engines, each capable of discharging into the service-tank 105,000 gallons per hour. These engines are supplied with steam from the boilers of the main pumping-engines, and can be worked separately or together.

Within a few feet of the settling-reservoirs there is another independent engine and boiler-house for a second set of centrifugal pumping-engines, each capable of discharging from the settling-reservoirs into the service-tank 130,000 gallons of water through a 16-inch delivery main. These engines, which can be worked either together or separately, are supplied with steam from an independent boiler in the same house. They are placed immediately over another pumping-well, which intercepts the 2-foot 6-inch brick culvert above referred to, and by opening or closing the sluice-valve built in the culvert the water may either be retained in this well, or allowed to pass on to the well in the main engine-house. Moreover, in case of need, both sets of engines may be worked at the same time for supplying the service-tank.

In the independent engine- and boiler-house referred to in the last paragraph, there is a deposit-well and steam-engine for facilitating the clearing of the settling-reservoirs. These reservoirs are cleaned out three or four times a year by flushing the sediment in a semi-liquid state into a sump at the end of each reservoir. Thence it flows through 12-inch drain-pipes into the deposit-well, and it is afterwards discharged by the pumping-engine on adjacent low-lying land.

The approximate quantities, and the actual cost inclusive of culverts, by-passes, valve-wells, and other accessories, not specially mentioned, but exclusive of the cost of land, were as follow:—

Abstract of Quantities and Total Cost.

Service-Tank—			£.
Earthwork	cubic yards	5,260	1,738
Rough rubble	„	830	
Concrete	„	1,044	
Brickwork	„	730	
Masonry	cubic feet	535	
Ironwork and sundries			175
Cost per 1,000 gallons capacity = £1 18s. 5d.			£1,913

Filter-Beds—			
Earthwork	cubic yards	6,609	3,594
Rough rubble	„	1,733	
Concrete	„	1,869	
Brickwork	„	1,884	
Masonry	cubic feet	1,386	
Filtering materials			2,112
Ironwork and sundries			350
Cost per square yard of area = £1 8s. 6d.			£6,056

Clear-Water or Service-Reservoir—			£.
Earthwork	cubic yards	4,950	2,518
Rough rubble	„	560	
Concrete	„	963	
Brickwork	„	1,662	
Masonry	cubic feet	600	
Ironwork and sundries			420
Cost per 1,000 gallons capacity = £3 10s.			£2,938

Main Building—	
Engine and boiler-house, &c.	1,962
Iron roofs and sundries	605
	£2,567

Chimney for Boilers—			
Earthwork	cubic yards	900	690
Rough rubble	„	47	
Concrete	„	66	
Brickwork	„	252	
Masonry	cubic feet	18	
Ironwork and sundries			108
			£798

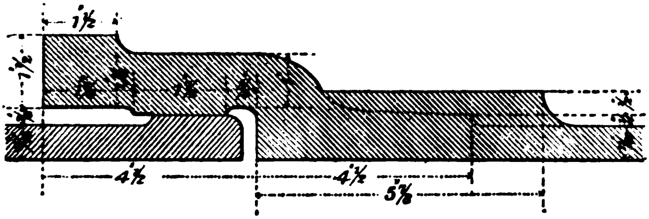
IV. Water-Tower.

It has been explained that the pumping main between the Yang-Tsze-Poo works and the water-tower is more than 3 miles long and is 20 inches in diameter, and that the necessary provision has been made for a duplicate main when required.

Sluice-valves are placed on the pumping-main between the Yang-Tsze-Poo works and the water-tower, at an average distance of 500 yards apart, so that any section of the main may be shut off for repairs or inspection. In such cases there is no interference with the general supply to the settlement from the water-tower. At the engine-house between the air-vessels and the main there is a reflux-valve, which, while permitting the free egress of the water while the engines are working, prevents ingress from the tower when the engines are at rest, and a second reflux-valve at the tower end of the main acts in like manner.

The general canalization of the principal and subsidiary distributing mains extends to all the roads and streets in the settlements and suburbs. The size of these mains varies from 18 inches on leaving the tower to 5 inches in diameter in the public roads and streets; but in passages, courtyards and alleys, the largest size used is 3 inches in diameter, and there are some as small as 1½ inch in diameter. In very wide thoroughfares, to avoid the necessity of traversing the streets from one side to the other with house service-pipes, a main is laid on each side of the road. All the distributing pipes and mains are laid with a minimum cover of 2 feet.

Fig. 1.



Pipe Joint.

The main and the service-pipes are made with turned and bored joints, *Fig. 1*, and are also provided with the ordinary socket-joint, which can be used in case of defect. No lead joints are used except for sluice-valves, special connections, or other exceptional cases. Before the pipes were laid, the joints were carefully cleaned and painted with thin red-lead paint. Each pipe, when laid, was rammed into position by the succeeding pipe, and in this manner one gang of men has in a single day laid as many as thirty 20-inch mains weighing 1 ton each. Before the trenches were closed the joints were tested under pressure, and it was found that the percentage of defective joints was so insignificantly small that it was not considered necessary to keep a special record. Any defective joints discovered were made tight with lead in the ordinary way. It should be noted, however, that several sockets were split by over-driving, and it was necessary to exercise great care to guard against mischief of this kind.

Sluice-valves are placed at the intersections of the roads and streets, and at convenient distances on long lengths of mains, so that any sections might be isolated and shut off for repairs or inspection, without interference with the usual supply elsewhere. Moreover, in case of several conflagrations at the same time in one or more districts (not an uncommon occurrence in Shanghai), the water may be concentrated in the locality of the fires.

The aqueducts across the creeks are all of the same design and vary only in length of span. That crossing the Soochow Creek is 261 feet long in three spans of 87 feet each. The aqueduct mains are 20½ inches in diameter, and are made of ¼-inch boiler-plate. They are in duplicate, and are supported by light bowstring girders. To provide for expansion, and in order that the mains may be used together or separately, there is a stuffing-box and sluice-valve at each joint connecting the aqueduct and pumping-main.

Four hundred and fifty hydrant posts are placed in the roads and streets; also a large number of private fire-valves. These are always available with a head of 100 feet of water for extinguishing fire and for other public purposes. They are under the control of an efficient volunteer fire-brigade—the police and officers of the municipality. To facilitate prompt action in case of conflagration, hose-reels are kept at convenient stations, in suitable position in the settlements, by means of which several powerful jets of water can be brought to play on the shortest notice.

All house-fittings are supplied by the Company, and the Company's workmen only are permitted to lay them. Tin-lined lead service-piping for domestic supply is the only class used. For economical reasons, strong galvanized iron pipes are used for gardens, long approaches, and in similar cases. None but screw-down draw taps are allowed, and every service-pipe is provided with a stop-valve placed immediately inside the building it supplies, while another stop-valve is placed in the street at the boundary of the consumer's property, and is under the control of the Water-Works Company only.

To facilitate departmental management, and to avoid difficulties which might arise in the absence of a general water-rate, and in consequence of the existence of separate municipalities and independent interests, the whole water-supply is served through separate meters. As has already been explained, the water on leaving the tower passes through a triplicate nest of 12-inch meters, which record the total quantity delivered for consumption, and also serve to check the quantity delivered from the pumping-station. A duplicate set of 12-inch meters, placed on the aqueduct over the Yang-King-Pang creek, records all the water passing into the French settlement. The water supplied to the American settlement (Hong-Kew) is registered in a similar manner by a set of 8-inch duplicate meters placed on the main where it crosses the Soochow Creek; and at the boundary of the English settlement, where the main crosses the Defence Creek for supplying the suburbs, there is a similar set of duplicate 8-inch meters. Similar means of checking the consumption in the native city will be adopted when the Chinese authorities consent to avail themselves of the Company's supply.

By this method of recording the quantity of water used, complete control is maintained over the consumption. Monthly returns of the water supplied and of the revenue received, together with a record of the number of consumers in each settlement, afford useful and interesting data, and enable close observation and comparison to be made.

All the main and service-pipes, also the sluice-valves, were coated with Dr. A. Smith's preservative solution applied at a temperature of 600°. The pipes were tested to 130 lbs. per square inch and the valves to double that pressure. The sluice-valves are double-faced with gun-metal, and fitted with screw-spindles and nuts of the same material.

The contract price for laying the mains and service-pipes, and jointing the sluice-valves and special connections, and testing the same when laid, including cartage from the wharf to the trenches, the excavation of the trenches, and the restoration of the roadway, was as follows:

COST of LAYING the PUMPING and DISTRIBUTING-MAINS, INCLUSIVE of ALL CHARGES, PER PIPE of 12 FEET.

Diameter	20 ins.	18 ins.	16 ins.	15 ins.	11 ins.	9 ins.	8 ins.	7 ins.	6 ins.	5 ins.
Cost . .	19*s.*	18*s.* 6*d.*	15*s.* 3*d.*	14*s.* 9*d.*	11*s.* 6*d.*	10*s.* 6*d.*	8*s.* 6*d.*	8*s.*	8*s.*	7*s.*

The total length of mains and service-pipes of all sizes laid in the settlements and the suburbs is nearly 39 miles, and the total weight of the same 5,460 tons, and there are six hundred and sixty-five sluice-valves of various sizes.

V. WATER-RATES.

Before the opening of the water-works there were several disastrous conflagrations in Shanghai. In August, 1879, a fire broke out in the French settlement, and resulted in the destruction of more than one thousand houses, and in the loss of property valued at more than £425,000. The rates charged for insurance, in those days, on foreign property varied from ½ to 1 per cent., and on native property from 1½ to 5 per cent., and in cases of specially hazardous risks even these rates were exceeded. The rates now charged on foreign property vary from ⅛ to ½ per cent., and on native property from ¾ to 2½ per cent., the reduction being admittedly largely due to the facilities afforded by the Company for extinguishing conflagrations. This reduction in insurance rates affords to the merchants and property-owners a direct aggregate annual saving of not less than £90,000 to £100,000.

The other advantages conferred on the settlements by the Shanghai Water-Works may be conceived when the system of water-supply superseded by the Company is described. Water drawn from the rivers, creeks, or pools, too often without the slightest regard for the outlets of drains or other contaminating influences in the immediate proximity, was purchased at high prices from coolies. It was delivered in buckets to the houses of the consumers, and it was there placed in large kongs (earthenware jars), and by exposure to the sun and the free use of alum, the earthy matter held in solution was precipitated, and thus the water was made apparently more suitable for domestic purposes. A limited supply of filtered water was obtainable from a small local company, and was delivered in carts at the houses of customers, at rates varying from 6*s.* 6*d.* to 13*s.* per 1,000 gallons. It is scarcely necessary to add that the water supplied at these high rates was within the reach of only a limited number of the inhabitants of Shanghai. The boon conferred on the community by the Company will be apparent when it is stated that, from the date of starting, in August 1883, to December 1887, the Company's average receipts for 2,447 million gallons of water delivered to the community on the constant-service system, were at an average rate of 5·7*d.* per 1,000 gallons.

In the Anglo-American settlements the rate now charged to the householder for a constant and unlimited supply is settled by mutual contract, and varies according to the estimated requirements of each consumer. The contract contains restrictions regarding abuse and wilful waste, but these stipulations are too often disregarded. For business purposes the supply is through meters, at rates varying according to the quantity used. The Anglo-American Municipality pays for the water necessary for extinguishing conflagrations, watering roads, and the public services a set sum per annum; and for this sum it is supplied with a given quantity per diem, an extra charge being made for any in excess.

Up to the present the municipality has not exercised its power to enforce a general water-rate, though the assessment of such a rate would obviously be in many respects an advantage, and more satisfactory to the whole community. It would result in equalizing rates, and reducing them proportionally to all consumers.

The French Municipality pays to the Water Company an agreed sum per annum for the whole supply necessary for that settlement. Self-closing wall hydrants are placed in all the streets at convenient distances, and residents can draw water at all times for domestic use free of charge. The natives appreciate this advantage, and one result of this arrangement is that the percentage of unoccupied houses in the French settlement is much less than it was formerly, obviously to the detriment of property-owners in the Anglo-American settlements. It must be added, however, that though this system is most commendable and has many advantages, it is also open to many grave objections; the quantity of water used and wilfully wasted is enormously in excess of the reasonable requirements of the number of persons supplied.

It would be foreign to the purposes of this Paper to detail the many devices resorted to by the Chinese water-guilds to prevent the Company from supplying the native city with water, and thus depriving them of the lucrative employment they find in retailing, at high prices to consumers, water of the most nauseous description, collected from stagnant pools and from the creeks at all stages of the tide. The most refined and complete form of guilds and trade combinations is to be found in China, and the power of these organizations is almost absolute. The water-mains are laid up to the gates of the Chinese city, and provision is made for their extension within the city walls, but in consequence of the opposition of the water-carriers, trade guilds, and native officials, it has been impossible to obtain permission to proceed further with the work.

VI. Conclusion.

The Shanghai Water-Works Company was registered with a capital of £100,000. However, to meet the cost of enlarged works and extensions necessitated by the growth of the port since the inception of the project, the capital was subsequently increased to £120,000. A further augmentation of capital by £20,000 or £25,000 will be necessary for additional pumping-engines, filter-beds, &c., if, as is probable, the Anglo-American Municipality should eventually strike a general water-rate as an equivalent for a free supply to the whole population of those settlements. Allowing for the additional £25,000, making the total cost £145,000, and taking, as previously stated, the total population to be supplied at 169,338, exclusive of the native city and population afloat, the expenditure amounts to 17*s.* per head; this is irrespective of any allowance for the cost of surplus land, or for the provision already made for the future extension of the works; and here it may be noted that freight alone, on the mains and heavier parts of the plant from England to Shanghai, amounted to nearly 30 per cent. of the contract cost in England.

The works were commenced in Shanghai in the month of August, 1881, and were inaugurated for public service by His Excellency Li-Hung-Chang, the Viceroy of Chili, in July 1883, exactly two years after the commencement. The severity of the winters in 1881 and 1882 caused serious interruption to the progress of the work; and the damage done by two typhoons, the first of which carried away a part of the river embankment, and completely flooded the low-land excavations at the Yang-Tsze-Poo works, also delayed their completion.

Messrs. S. C. Farnham and Company, of Shanghai, were the local contractors for constructing the work, subdivided into nine separate and distinct contracts. In the progress of the work, unexpected difficulties were encountered, and the Author can speak with much satisfaction of the praiseworthy zeal and resources Messrs. Farnham brought to bear in surmounting the difficulties met with.

The water-tower, mains, and service-pipe, aqueducts, sluice-valves, hydrant-posts, and all ironwork, were supplied by Messrs. R. Laidlaw and Son, of Glasgow, under six separate contracts.

The main pumping-engines and boilers were made by Messrs. Hathorn and Davey, of Leeds. The engines have delivered from the works to the water-tower 2,447 million gallons, at a cost for repairs and renewals almost fractional.

The two sets of centrifugal pumping-engines, for the intermediate lift from the settling reservoirs to the service-tank, were made by Messrs. J. and H. Gwynne; they have been in constant use.

The meters and house-fittings were supplied to the Company by Messrs. John Tylor and Sons.

This Paper is accompanied by several drawings and photographs, from a selection of which Plates 6 and 7 and the *Fig.* in the text have been engraved.

(*Paper No. 2429.*)

"Tytam Water-Works, Hong-Kong."

By JAMES ORANGE, Assoc. M. Inst. C.E.

INTRODUCTION.

PREVIOUS to the construction of the Tytam Water-Works, the city of Victoria, Hong-Kong, containing about one hundred thousand inhabitants, was dependent for its water upon the Pokfoolum Storage-Reservoir and various small streams, together with wells and springs in the town, the supply being equal to a daily allowance of 5¾ gallons per head.

From an exhaustive report, presented in 1885 to the Legislative Council of Hong-Kong by the Surveyor-General, Mr. John Macneill Price, most of the following information has been obtained.

In 1873 Mr. Price was instructed to submit schemes for an increased water-supply to the city, who, after a thorough examination of the whole island, recommended the formation of a storage reservoir, with a capacity of 300,000,000 gallons, in the Tytam Valley, by constructing an earth-and-puddle dam across the gorge, the water to be conveyed to the city by a tunnel through the intervening range of hills, and cast-iron pipes from the outlet to the existing store tanks of the city.

In spite of the urgent need for increased water-supply no action was taken by the Government till 1882, when the requirements of the Chinese population, and the grave sanitary dangers involved by the water famine which prevailed among the poorer classes every winter, caused the Tytam project to be sanctioned by the Colonial Office; and Sir Robert Rawlinson, K.C.B., was appointed Consulting Engineer. Mr. Price being in England, machinery was purchased and men were engaged for the tunnelling operations. The designs for the dam at Tytam were completed; but in consequence of the height, the original idea of an earthen dam was abandoned, and masonry decided upon. The Author joined the Hong-Kong Civil Service in January 1883, and was appointed Resident Engineer for the works.

The different works may be classed under four headings:—

I. The formation of a storage reservoir in the Tytam Valley, by the construction of a concrete dam across the gorge, together with a by-wash, roads, &c., at Tytam.

II. The boring and completing a conduit tunnel through the Tytam range of hills, with inlet and outlet works.

III. The construction of a masonry conduit, winding along the mountain from the tunnel outlet to the filter-beds at the Albany Valley.

IV. The construction of filter-beds and a service-reservoir at the end of the conduit in the Albany Valley.

I. TYTAM RESERVOIR.

The reservoir is about 5 miles from the city of Victoria, and is situated to the eastward of the Tytam range of hills (Plate 8, Fig. 1). A steep mountainous road, rising to 1,000 feet above the sea, has to be traversed to reach the valley. Materials were brought from a bay about 1½ mile from the valley, up a road with occasional gradients of 1 in 3.

The drainage area of the valley is about 700 acres. The average rainfall is about 60 inches during the south-west monsoon, from April to September inclusive. During the dry season, or north-east monsoon, there may be no rain, therefore six months' water-supply must be provided. The area of the reservoir is 27 acres, and it contains 310,000,000 gallons; an extension of 10 feet in height of dam would give 90,000,000 gallons more.

There is a perennial stream in the valley, which may be reckoned to yield 200,000 gallons per day; the old supply from Pokfoolum Water-Works, 530,000 gallons, and the Tytam supply 1,700,000 gallons, make a total of 2,430,000 gallons as the volume of water capable of being supplied to the city daily.

The volume of water required by the city of Victoria, especially during winter, is less than the requirement of an English town, there being practically no water-closets; all fæcal matters are carried away in pails, the bulk of the population being Chinese. Previous experience had shown that 5·75 gallons per day was sufficient, and this quantity was supplemented by water fetched from hillside streams. The Author considers that a supply of from 13 to 14 gallons per head per day would be advisable; therefore the works, as at present constructed, would suffice for two hundred thousand inhabitants, a number which will soon be reached, and by that time the extensions arranged for should be built. The Author believes that, during ordinary summers, Tytam would be able to supply 3,000,000 gallons per day.

The Tytam Valley is of irregular shape, with deep ravines. The valley is uninhabited, and the hills are mainly of rock and disintegrated granite, clothed for the most part with coarse grass and bracken; the water is soft, and of remarkable purity. The heaviness of the rainfall, however, causes a great deal of sand and detritus to be washed from the hills. The water in the reservoir is therefore turbid at such times, and filtering is an absolute necessity.

TYTAM DAM.

The original design was for a masonry dam, with outside curved face; but a very short experience of Chinese masons proved the impossibility of trusting them to bed stones in mortar, and to execute the class of work without an amount of European supervision which would be impracticable; therefore it was decided to construct the dam entirely of concrete.

The site chosen was where there was a bed of rock exposed at the bottom of the stream. The rock was a dense, hard white granite, with numerous joints and fissures. A dyke about 5 feet wide, of soft greenish clay, charged with water, crossed the dam parallel with the stream. This dyke was of indefinite thickness; it was therefore excavated for about 10 feet, and filled in with rich cement concrete.

It may be convenient to give here a description of the foundations. The bottom, as far as the west side of the valve-well pier, was hard rock. At this point joints occurred in the face, filled with black manganese oxide powder, mixed with disintegrated granite (similar joints being met with at the tunnel about this locality); they were dug out with chisels and filled in with cement mortar and very fine concrete. The rock, probably a huge boulder, commenced at about 15 feet from the upstream or south side of the excavation, and at this point decomposed granite of an extremely awkward nature was found. It was too hard to pick, and yet difficult to blast. This width of decomposed granite occurred to the top of the dam, making a kind of large rabbet, of which the deep tongue was against the upstream excavation. The rock, with similar joints, lasted to the level where the foundations were taken in the decomposed granite.

The latter was so hard that even if water reached it from the reservoir, no softening was likely to take place; it was therefore decided to build the sides of the dam on this foundation, care being taken that the decomposed granite should be nowhere nearer than 15 feet from the surface of the ground on the hillside.

The eastern side was of still more varied character. The bottom bed rock was cut off by a vertical dyke of hard basalt, and the formation became a mixture of huge boulders of dense white granite, having decomposed granite joints and beds. A lode of hard white porcelain clay was met with at the south side; it was partially excavated, and being so hard and occurring only at the outer edge, concrete was laid on it. The decomposed granite foundations were crossed with trenches, so that no part of the base should be level.

Precautions were taken to have drainage channels and conduits constructed on the foundations, and from the concrete leading to the gutters on the outer face of the dam, to get rid of any water which might find its way to the foundations. Several springs were met with, both in the bed rock and at the sides, and these were led to the outside of the dam in pipes.

As the water was retained in the reservoir, experiments were made with the ground at the hillsides to see if the material was affected by the water. At the west end, near the centre of the valve-well, opportunity was taken of a deep cutting, which had to be made while the concrete dam was in course of construction, necessitating the existence of steps in the older concrete, to make a circular pit up to the top of the dam, the decomposed granite foundation remaining exposed. This pit was examined after completion of the dam, and about 2 inches of water were found lying over the bottom; but the water did not increase, and the ground remained as hard as when opened out at first, under a head of 22 feet of water.

A 2-inch pipe was fixed in the concrete leading to the outside face of the dam, at the level of the foundation, at the west end. The end of the pipe was left open, and a heap of loose stones, covered with linen, made over the ground, so that the pipe was exposed to the naked foundation. With the reservoir full, equal to a head of water of 28 feet, a dribble of water appeared.

At the east end, at a base of 482·5 feet, a bore-hole 3 inches in diameter was sunk 35 feet through the disintegrated granite. With water outside in the reservoir at 479 feet, the level of water in the bore-hole was, at 467 feet, giving a head of 12 feet lost in going through the hillside.

The result of gauging the stream, before and after formation of the reservoir, was as follows:—

Gauge A was fixed 70 yards below the base of the dam.
B „ „ on river bed, on the east side of the dam.
C „ „ „ „ „ west side of the dam.
D „ „ on top of the pedestal block, and the water can be run into the tunnel.

—	Gallons per Day.			
	A.	B.	C.	D.
Reservoir empty, volume of stream.	384,500	6,000		
„ level, 423 feet, dam closed	21,600	10,000	1,080	4,000
„ „ 483 feet before lining	303,000			
„ „ 485 feet after „	207,000			
„ full, 496·3 feet . . .	222,000	48,000	129,000	190,000

Most of the water from the face of the dam, or D, proceeds from the channels placed against the hillsides at the foundations, the absolute leakage through the concrete work of the dam being 6,000 gallons per day. The daily loss of water when the reservoir is full amounts, therefore, to 222,000 gallons. The gauges B and C are close to the dam, and the difference, 45,000 gallons, comes from springs which have appeared in the east bank since the formation of the reservoir. All the gauges are affected by the level of the water in the reservoir, and show clearly that water percolates through the rock at the sides of the dam and at the foundations.

The surface of the bed rock was broken up into an irregular form by putting in shallow shot-holes. No dowel was considered necessary, and no leakage can be traced to the want of contact between the concrete and bed rock.

The rock surfaces at the base, having been tested with hammers and found solid, were covered with a coating of cement mortar, 2 inches thick, composed of 3 parts of river sand to 1 part of Portland cement, and mixed in a mortar mill. The first coat was mixed stiff in the mill, and wetted on the rock so as to form a grout into the joints. While the coating was wet, fine concrete, 18 inches to 2 feet thick, was laid, and the whole rammed with wood rammers. The mortar was rather superfluous, as the fine concrete was practically a mortar, being composed of 3 parts of sand, 2 of granite broken to about ¾-inch square, and 1 part of Portland cement.

All decomposed granite or clay beds were covered with a thick grouting of Portland cement and sand in equal portions, and extra fine concrete was laid on at once; the joints to the boulders or rock were carefully raked and pointed with 1 to 1 cement mortar, concrete being always laid against wet mortar. All boulders covered with a skin of decomposing or weathering granite were rough punched with chisels till the solid stone was reached.

The total height of the dam (Plate 8, Figs. 2 and 3) is 120 feet, the greatest depth of water 109 feet. The dam proper is 95 feet high, 23 feet 6 inches thick at the top, and 62 feet 6 inches at the base, and an extension of 10 feet in height is provided for. The foundation block is of rubble concrete, with cement-rendered face. The dam is of rubble concrete, with fine and extra-fine concrete skins. The inner face is of ashlar, and the outer of rubble masonry. The principal dimensions and particulars of the reservoir and dam are given in the Appendix. The inner face of the foundation block is vertical, the outer face has a batter of 3 to 1, the ashlar stone front being a facing only, and detached by a lining of loose rubble stones from the concrete. The mass of the block is of rubble concrete, the rubble stones being omitted within 6 feet of the extra-fine concrete skin, which was 3 feet thick and rendered with two coats of cement mortar.

The ashlar of the inner face is rough-punched, laid in 1-foot courses, each course alternately header and stretcher, the latter being about 4 feet long, and the former 1 foot square, and 1 foot 9 inches long; the tails of the headers and backs of the stretchers were left rough. Every stone was lifted by claws and placed on a thick bed of 3 to 1 cement mortar, and knocked down on the bed with wooden malls. The face and vertical joints were fine-punched, the beds rough-punched; the vertical joints had dowels cut 1½ inch square, and filled with 1 to 1 liquid cement mortar. All the joints were tuck-pointed, with a flat joint ¾-inch wide, as the work progressed.

The outer face is of rough quarried rubble stones, generally laid one stone thick, the concrete backing holding the stones. The joints were pointed with cement, numerous holes being left in the pointing for drainage. The top of the wall was rendered with cement, and a gutter was formed leading to a semi-circular channel in the centre of the elevation. The down drains were covered with cast-iron, to prevent the water splashing over the wall and benches, and lead to a drain at the base of the dam.

The inner face of masonry is lined with extra fine concrete at least 2 feet thick from the back of the ashlar stones. The surface of the old concrete was thoroughly cleaned and roughened with picks, and the bottom was grouted with liquid cement. The ashlar face was laid two courses at a time, and the fine concrete was laid 6 inches above the level of the top of the masonry, therefore the extra fine concrete was deposited between two solid walls and was well puddled with flat iron rammers. This concrete was composed of 3 parts of sand, 2 of broken stone, and 1 part of Portland cement, and was hand-mixed always with a plentiful amount of water, experience proving that an excess of water always came to the surface, and in the hot climate soon dried up. Before the cement was quite set, the top crust was scraped off, and the traffic of coolies and stone-setters helped to still further consolidate the concrete. The impermeability of the dam depends on this inner skin, therefore extra care and precautions were taken that the layers should thoroughly adhere one to another. A thickness of 2 feet of the fine concrete is continued, from the centre around the ends of the excavation for the dam, at the base to three-quarters of the width of the excavation, and at the top to about one-half of the width of the end.

The next thickness is composed of concrete of similar composition to the matrix of the rubble hearting; it was well rammed and laid in 12-inch layers. The rubble concrete being higher formed one wall for the concrete, the inner side being made against boards.

The mass of the dam and the foundation block is composed of granite rubble stones embedded in a matrix of concrete. The mixture of concrete at first was 2 parts of sand, 2 of ¾-inch cube, and 3 of 1½-inch cube broken stone, to 1 part of Portland cement; but the sand being sharp and the stones clean, an additional part of sand was afterwards given. At 428 feet level, the stones being broken to a uniform size of about 1-inch cube, 4 parts of stone were used. From 458 feet to the top the concrete-mixer was used; the composition varied from 4½ to 5 parts of stone, 3 of sand and 1 part of cement. The Author is inclined to think 3 parts of sand, 5 of stone and 1 part of cement a good proportion with suitable materials.

The method of working was as follows:—The bankers were placed on the higher layer of concrete, facing towards the space to be filled; the floor of old concrete was thoroughly scrubbed, wetted, and any smooth surfaces roughened with picks; if flood water had been over the concrete or the surface had been rendered muddy by earth, it was then painted over with a grout of liquid cement. One or two mixings of a banker were next spread on the floor, and the stones, cleaned and wetted, were carried by coolies and placed on end, and well worked into the wet concrete. The average size of the stones was about 2 cubic feet, ranging up to a maximum of 4 cubic feet. They were generally placed with the smallest end downwards. No stone approached another nearer than 3 inches. A row of stones having been fixed, the concrete was thrown between them, leaving their tops exposed above the surface of the concrete, and thus making a rough top to the dam.

The bankers were always immediately behind the work carried on; the concrete could thus be mixed fairly wet, and any drainings and droppings of concrete were immediately trodden into the fresh concrete by the traffic of coolies about the bankers; the concrete was well rammed between the stones with iron rammers, consisting of a 1-inch pipe with cast-iron end about 6 inches long, 3 inches in diameter, and chisel-pointed. Each layer of rubble concrete was from 1 foot 9 inches to 2 feet thick; the concrete was mixed with an excess of water. Part of this concrete had to be blasted, and splitting occurred across the concrete and stones, showing a very good adhesion of the two materials. The concrete formed an average of 60 per cent. of the mass, and the rubble stone 40 per cent.

For hand-mixing, all materials were brought on the dam in iron pails of equal size, so that no gauge-boxes were required; the sand and cement were first mixed dry, and then wetted; the stones were thrown equally over the surface of the mortar which was wetted, and the concrete was turned over into a heap with shovels, while one man with a three-pronged fork kept mixing the materials together; the heap was again spread and reformed, and thrown into the work, water being added in dry weather.

This method is usually adopted with local lime concrete, and a very good mixing of the materials is ensured; it was, however, difficult to proceed quickly with the work. As the dam narrowed, the three different mixtures of concrete, the number of coolies engaged, and the space occupied by the bankers caused crowding; therefore a concrete-mixer was purchased from the Kowloon Dock Company, into which the sand and stone as well as the cement were fed by worms. A simple contrivance of disk-crank, and connecting-rod actuating a lever ratchet, the length of which could be altered, enabled the proportions to be easily changed. The machine worked very satisfactorily. It was fixed with two Marsden stone-breakers at a site above the top of the dam; the breaker screens delivered the stone on a stage at the level of the top of the mixer. On this stage were the three compartments for stone, sand, and cement. The breakers were worked by a 12-HP., and the mixer by an 8-HP., portable engine.

The concrete was discharged down a shoot lined with sheet-iron on to a platform on the dam; a coolie with a fork remixing it as it was delivered. The concrete was carried in iron "baskets," and when deposited was sprinkled with water and rammed. The surface of the concrete was kept well wetted during dry and hot weather.

The broken stone was composed of hard white granite obtained from boulders, quarries, and the tunnel tip. The products of the stone-breakers were supplemented by hand-broken stone. The machine-broken stone was passed through screens with holes 1¾ inch in diameter, so that the stones were about 1 inch cube; the hand-broken stone which was used for the extra fine concrete ranged from 1¼ inch cube to ¾ inch cube. The sand made by hand-broken stone was used with stone, but that produced by the stone-breakers was sifted and used as sand.

The stone for the rubble blocks of the concrete was obtained from boulders in the bed of the stream, from ravines and from quarries up the creeks of the reservoir. As the dam was raised, the flood culvert was temporarily stopped with timber, flap-valves were worked by chains from the surface, and water was allowed to accumulate to a height of not more than 15 feet from the top of the dam, except that in one flood the water rose to within 18 inches of the top. Wood flats, carrying about 20 tons, were employed to bring the stone to the dam; the blocks were hoisted in wood trays by a steam-crane.

The stones were always angular and of irregular shape, being used just as they were quarried or cut up; the sizes ranged from 2 to 4 cubic feet, the greater portion being 2 cubic feet. Each stone was well washed before being put on the boat, and every tray-load well wetted before hoisting. Small stones were occasionally inserted in the larger spaces between the rubble stones, so as to economise the concrete. Very careful supervision had to be exercised over the rubble stones, as it was impossible, till blasted, to tell whether a boulder would prove sound or decomposed. The sand was a source of great trouble and expense. At first there was abundance in the stream bed, being the washing down of the decomposed granite and hills; it was so sharp and clean that without a large quantity of cement water would not be retained. This supply soon came to an end, and the bulk had to be fetched from near Tytam bay, or nearly 500 feet below the level of the dam. The stone-breakers were of great assistance, and by using old jaw-plates a great deal of sand was produced. Where closeness is required rather than extreme strength, such as for a dam, the Author prefers sand a little loamy, or rather mixed with softer and finer material, such as the siftings of broken stone or decomposed granite. The top layers of sand obtained from the beds of streams after floods were of excellent quality, the finer portions being deposited by settlement. Briquettes of cement and decomposed granite, as compared with cement and sand, were very nearly equal in strength. Cement sets extremely well with the greasy red earth of the country, even under water; care was therefore taken that the sand, if very sharp and clean, should be mixed with fine siftings from the stone-breaker.

The Portland cement was obtained, with the exception of a small quantity bought locally on an emergency, from England, through the Crown Agents for the Colonies. It was stored in Victoria and sent out to the works as required, a store for containing about 500 casks having been built at the site of the dam, and one capable of containing about 1,200 at the landing pier at Tytam bay. The Author instituted a comparison of cement tests, Appendix III, and occasionally slightly altered the amount of cement used in the concrete, according to the tests obtained and the apparent action of the cement in practice.

The condition of the cement on arrival was, on the whole, very good, owing to the excellent mode of packing adopted by the Crown Agents. Occasionally the contents of casks were hardened by damage done on shipboard.

A great difference was noticed in some cases in the quantity of lime which exuded from the concrete on the face of the dam. One shipment of cement in particular gave a great deal of deposit; and though the mixing at the time was being effected with river sand and stone-breaker sand, the surface of the concrete newly made was coated by a great efflorescence of lime.

VALVE-WELL.

The valve-well (Plate 8, Fig. 4) is 11 feet by 5 feet, faced with granite ashlar, in 1-foot courses set in 2 to 1 cement mortar. Large stones were fixed, with chase and horn cut to receive the cast-iron midfeather plates 3 feet high. The midfeather made a wet compartment 5 feet by 4 feet, and a dry compartment 5 feet by 6 feet. The plates had sheet-lead horizontal joints, and the joints against stone were made by lead, poured in and well caulked, a thickness of $\frac{3}{8}$ inch to $\frac{3}{4}$ inch being allowed; the dowels of the jaws of the plates were filled in with iron-cement. This joint has answered well, but one or two of the beds of the lower stones are not quite water-tight, as a hole had to be cut at the level for one of the floor-plate girders, leaving only 6 inches of stone to the joint; there the water under full reservoir pressure oozes through the stone. At every 21 feet there is an inlet into the reservoir, and one length of 18-inch cast-iron pipe bedded into the concrete. The end of the pipe where it enters the water has a bevel face, with lip and holes, prepared for a cover if required; the 18-inch water-way was continued in concrete to the wet well. Opposite the inlets into the valve-well are openings in the mid-feather; 18-inch sluice-valves are fixed at these openings in the dry compartment, and communicate with the vertical down pipe. The valves, five in number, are worked from the surface by suitable gearing and rods. The dry well is furnished with floors at each valve-level. As a rule the valve nearest the surface is used.

It was intended to have a valve-house over the well; but, as an extension of the dam is contemplated, it was resolved to cover the well with an iron plate, leaving the valve-rod standards exposed. The cost of the ironwork was £873 exclusive of the inlet pipes.

A pier is built projecting on the inner face about 22 feet, and 43 feet wide, consisting entirely of rubble concrete faced with ashlar masonry, the extra fine concrete inner skin and the fine concrete of the dam continuing in a straight line to the valve-well which is surrounded with extra fine concrete.

DRY CULVERT.

A dry subway, or culvert 6 feet high by 4 feet wide with semicircular top, is constructed through the dam, and leads from the valve-pit outside the dam to the dry compartment of the valve-well. The walls and arch are constructed of extra fine concrete 3 feet thick. Advantage was taken of the subway to lead some pipes from the foundations at that level, and also from the concrete, but no water issues. A valve-pit of ashlar masonry was made outside the dam with two 18-inch sluice-valves, forming a by-pass to the stream. The pit is covered with cast-iron perforated floor-plates on which are indicator pillars, and worm-gearing to work the valves. The by-pass was extremely useful during construction by passing off flood-water. The water is conveyed to the tunnel inlet through 18-inch cast-iron pipes 9 feet long by ¾ inch thick, and weighing 12 cwt. 25 lbs. each.

The foundations for the extension of 10 feet at top of the dam were prepared, and the extra fine concrete inner skin was carried into the back of the excavation. Against the bank water-tight concrete walls were made, and faced with stone laid in cement mortar. A recess was left in the face of the end walls 6 feet square to act as a dowel; therefore, when the extension of the dam is carried out, the pointing of the end walls needs to be raked out, and the extension can be built against the walls, the sides being now complete.

The surface of the cement concrete of the dam was left rough; two longitudinal grooves 3 feet by 2 feet were filled in with dry loose stones, and a false skin 9 inches thick of lime concrete forms the present surface.

A parapet, 4 feet high, is formed on the reservoir side, being three courses of ashlar similar to the inner face backed with extra fine concrete. A fine-punched granite coping, with chamfered edges, 2 feet 9 inches wide by 12 inches thick, is laid on top in lime mortar with vertical joints in cement, so that the stones can easily be taken up and used for the extension. On the outer side there is a coping 3 feet wide by 12 inches thick, with a gutter and an iron railing 4 feet high, composed of 1½-inch wrought-iron pipes and cast-iron standards 45 lbs. in weight. The standards are bolted by screw-bolts to cast-iron dowels leaded in the coping.

As the hills were of so irregular and porous a nature, it was decided to puddle the banks inside the reservoir area for a distance at top of about 60 feet from the dam face, and widening out to 120 feet at the bottom. The hillside being steep, retaining walls were built at intervals, the lower walls of single face stones set in cement mortar, or backed with 18 inches of extra fine concrete, and laid on a similar concrete base; the upper walls were lime-mortar walls on lime-concrete foundations, backed with clay puddle about 2 feet thick.

The hillsides were cut in narrow steps, all roots of grass and shrubs being taken out, and the spaces next the dam, between the face and the excavation, were cleared out and filled with lime concrete; the earth was then covered with clay puddle from 18 inches to 2 feet thick, and well worked by treading with the bare feet of the coolies. Excellent puddle came from Whampoa, about 80 miles distant; it weighed 102 lbs. per cubic foot. On the surface of the clay a layer of 18 inches of red earth of a close and greasy nature was laid damp and well rammed, and on this dry stone pitching was placed, averaging 9 inches thick, and roughly bedded in lime mortar. The clay was well lapped over the concrete foundations of the toe walls, and at the edge of the area of pitching a dowel about 2 feet deep was cut into the earth and filled with clay puddle. In the bed of the stream, at the upper end of the pitching, a trench was excavated about 18 feet deep through the sandy and rocky bed. Great difficulty was experienced in keeping water out; there was no sign of a bed rock, therefore the trench was filled with puddle carried up to the bank-sides. The pitching, within a radius of 40 feet from the scour pipe, was laid in cement mortar and pointed. The entrance to the flood culvert was protected by a grating of 24-lb. rails fixed at a slope of 60° and placed 6 inches apart.

The banks on the outside of the dam were formed of material excavated in preparing the foundations and roads. Heavy retaining-walls, principally of dry rubble stône, were built on the bed of the stream and toe wall to the west bank. The west bank was piled every 10 feet vertical height with 4-inch fir piles placed 18 inches apart. All banks were turfed; steep sides were pegged at every sod with two bamboo slips. The east lower retaining-wall on the bed of the stream is provided with a conduit channel at the back, communicating with the concrete face of the foundation block, and serves to lead away the springs found on opening the foundation and in the banks. Catchwaters were constructed above the roads. The eastern catchwater, 3 feet wide by about 3 feet deep, delivers into the reservoir; the western catchwater, owing to the bad nature of the foundation, necessitated some heavy walls; the water passes under the road down a steep slide, the walls of which in places were over 25 feet high; this catchwater is 4 feet wide, and delivers into the old stream bed.

A cast-iron scour pipe 2 feet in diameter is fixed in the flood culvert originally made in the foundation block. The pipe commences 53 feet from the inner face; brickwork in cement is built 3 feet thick around the pipe at the head, and chases having been cut in the old concrete, the space between the old concrete and the pipe is filled with extra fine concrete. A wall and platform is built faced with ashlar, and backed with rubble concrete, a pit being made to take the 2-foot sluice-valve and 9-inch by-pass; the pit is covered with a cast-iron grating. The concrete of the foundation block, which was originally built with a 1 to 3 battered face, is refaced with a vertical ashlar front backed with 1 foot of extra fine concrete, a space being left against the old concrete which is filled in with loose rubble stones; 2-inch pipes conduct the water issuing from the foundation block to the front of the scour-valve pedestal.

Roads from 8 to 10 feet wide lead round the hill from the by-wash to the dam and police station, also to the tunnel inlet; the greater part is covered with fine concrete 6 inches thick, and all have concrete channels rendered with cement and furnished with drains. Railings are fixed on the retaining-walls, which are built generally of dry rubble stone, and coped with fine-punched granite coping 6 inches thick.

BY-WASH.

The by-wash is constructed at the west side of the reservoir, and leads into a small valley parallel to the Tytam Gorge. The bottom of the valley is about 20 feet below the top level of the reservoir. At the suggestion of Mr. Price, a scheme was drawn out by the Author for making a subsidiary reservoir in this valley; but the extension of the dam having been abandoned for the present, the by-wash reservoir was also put aside; the proposed reservoir would give about 20,000,000 gallons extra at a cost of about £5,000.

The extreme width of the by-wash is 100 feet, and the sill is 2 feet below the level of the top of the dam; heavy cutting was entailed at the ends in making the roads, about 23,000 cubic yards of material having been excavated and tipped in the valley below the proposed subsidiary reservoir, the tip being held by retaining-walls, and being part of a necessary diversion of roads for the reservoir scheme.

The excavation for the sill was taken out to a depth of about 10 feet to the solid rock; the trench was filled with lime concrete, and the sill formed of rough-punched granite copings 12 inches thick, and the floor of cement concrete; a slope to the level of the valley was formed of a layer of 12-inch rubble stones laid in cement mortar on a bed of 12 inches of lime concrete. A bridge was constructed 10 feet wide to take the mountain road to Stanley.

The cost of the by-wash, bridge, retaining walls, and diversion of road was £4,238.

II. TUNNEL, &c.

From the dam the water is carried by an 18-inch cast-iron pipe to the gauge basin at the tunnel inlet. The tunnel for the passage of the water pierces the range of hills which forms the backbone of the island, and leads from the Tytam Valley to the Wongneichong or Race Course Valley (Plate 8, Figs. 1 and 5). The length is 2,428 yards, the average width about 7 feet by 7 feet 6 inches high; it was made as small as could be convenient for working two columns and drills.

The level of the floor is about 400 feet above the sea, and the tunnel was constructed with a rise of about 3 feet to allow for drainage.

The ground was almost entirely a dense hard white granite, full of fissures and faces, both horizontally and vertically. At the Tytam end large granite boulders, with irregular jointed masses of rock and decomposed granite, were met up to 230 yards; a good deal of this part had to be lined. The rock being so irregular, and boring into any hillside being opposed to one of the most rooted prejudices of the Chinese, the average progress was only 14 feet per week. From this point hard white granite continued, with small interruptions, to the Wongneichong end. A shaft about 75 feet deep was sunk at 234 yards through granite to assist in ventilating the tunnel; and there was always a good draught between the end and the shaft, but the expense was hardly justified. At 235 yards a bed of reddish granite with molybdenite splashes occurred; at 283 yards, in very hard rock, a spring, yielding at first 6,000 gallons per hour, was struck, but it was practically exhausted in a fortnight; for 20 yards, however, there was a good deal of water in the rock, and progress fell from 28 yards for the month previous to 19 yards. The variations after this from the hard granite were trifling, being veins of rotten decomposed granite and of clay, occasional masses not exceeding 6 or 8 yards of reddish granite and disintegrated rock mixed with clay, several white spar veins about 3 inches thick, and about 6 yards of hard blue basalt.

PLANT.

The plant, which was all supplied by Messrs. Hathorn and Co., at first consisted of one horizontal air-compressor, with 10-inch air-cylinders, and one 12-HP. multitubular boiler and air-receiver, together with 2½-inch cylinder "Eclipse" drill-machines for each end. This plant, however, proved too light for the hard rock, and the two boilers and compressors were fixed at the Tytam end, and a new 30-HP. boiler and compressor with 16-inch air-cylinder erected at the Wongneichong end. Eight 3-inch drill-machines of similar pattern were used. The diameter of the air-main was increased to 3 inches for about 750 yards at each end, and was then reduced to the original size of 2 inches. An alteration was made to the ends of the drill-machines, consisting of a cast-steel block driven on the piston; the end is bored taper to receive the drills, which are turned to fit. They were then placed in the block, and the first movement of the machine fixed the drill, which could be easily removed by a cotter driven into the slot of the block. This end kept the drill perfectly true with the axis of the machine, and made the boring far easier. The machines were mounted on hydraulic columns. No holes were drilled deeper than 3 feet; the diameter of hole at the commencement was about 2¼ inches, diminishing to 1½ inch at the point. The drill-machines gave every satisfaction, only eight were used, of which two were worn out, and six remain in good order. The automatic feed was never used. The Author can strongly recommend the "Eclipse" drills if kept in thorough working order. The machinery was placed in wood houses, and a fitter's, a blacksmith's shop and stores, were provided at each end. Day-work was first adopted so as to train the Chinese labour; besides two English fitters there were seven British miners. A great deal of trouble was experienced with the miners, and their engagement being fortunately only for two years, the bulk of the work was afterwards done by Mr. Cook, the foreman mechanic, assisted by one European engaged locally. Work was carried on in three shifts of eight hours each; and, with the exception of breakdowns, cessation of work only occurred at Christmas Day and for the Chinese New Year—a festival when work is stopped for about three weeks.

The Chinese hands employed at each heading, for each shift, were: one foreman, three machine-men, and about six labourers; one engine-man, smith, hammerman, fitter, and store-boy. A spare foreman and engine-man, two or three machine-men, a store-boy, and occasionally a fitter were also kept to replace sick men. After a short experience of day-work, a contract was let for the supply of labour inside the tunnel to a Chinese contractor at £2 5*s*. per lineal yard; two contractors ran away, and Mr. Cook undertook the contract at the same price from November, 1886. The price was ample, but the difficulty of obtaining men was great, and the wages paid for underground labour were very high compared with wages aboveground; the want of management or foresight also entailed a loss where a profit should have been obtained.

The explosives were principally Nobel's dynamite in 1¼-inch cartridges; a little German dynamite and blasting gelatine were tried. The Author found no advantage from using the latter. The fuze was principally Bickford's white tape fuze and Nobel's treble-force detonators. Strong concrete magazines with iron doors, wood lined, were built at each end, small quantities of explosive only being kept in iron safes at the stores at the tunnel faces. Bickford's electric or simultaneous fuzes were tried, but no advantage was gained; by cutting off the fuze to the same length, simultaneous firing could be practically obtained as the holes were so close to one another.

An average of about fifteen holes were drilled each shift. The fuzes were cut to different lengths so that the holes could be exploded to advantage. After several trials it was found best to take out a centre and then the sides; the rock at times was so refractory that forty-two holes have had to be drilled and blasted to remove 2 feet of heading, and the consumption of dynamite was very large. For such rock the 3-inch machines even were too light, 3½-inch or 4-inch should have been employed; but the Chinese cannot handle heavy weights, therefore the 3-inch machines were considered heavy enough.

Advantage was gained by plugging up the holes with wet sand or clay, and bottom holes sloping downwards were filled with water. The holes of one shift were never all blasted at one time, two or three lightings being made. The Chinese joss-sticks, used in the temples, were extremely convenient for lighting fuzes, as they keep continuously smouldering. Candles of local make were used in the tunnel, and castor-oil was employed for engines, and nut-oil for lamps.

PROGRESS.

Work at the Tytam end was started on the 3rd of March, 1883, with the small compressor and 2½-inch drill-machines, and with the two small compressors and 3-inch machines. Up to February, 1885, when 452 yards had been completed, the average progress during working time was 21 yards per month. From February, 1885, to the 15th August, 1887, when the headings met, the working time was two years and four months, and the progress 811 yards, equal to an average of 30 yards per month, or a gain of 9 yards monthly by the use of the larger machines. Work at the Wongneichong end was started on the 6th of July, 1883, with one small compressor and 2½-inch machines, and with the larger compressor and 3-inch machines in November, 1884. For the first fifteen months the progress was 300 yards, equal to 20 yards per month; from then till completion, a working time of thirty months, the progress was 866 yards, equal to an average of 27 yards per month for the 3-inch machines, or a gain of 7 yards per month. The total time taken in driving the heading was forty-seven months, the average for each end being about 25·8 yards per month, or 6·3 yards per week.

The consumption of dynamite was about 25 lbs. per yard, with 6½ coils of fuze and 50 caps; and of coal 5,406 tons, principally Takasima (Japan) lump. From experiments made with Newcastle (New South Wales), Welsh, and Japanese coal, the latter was found far the cheaper and just as suitable for the work. Japanese coal is almost exclusively used in the Hong-Kong factories, and the turn out of the Takasima Colliery is about 1,500 tons a-day.

ALIGNMENT.

The tunnel was first set out over the hills roughly, piers were built at the various points shown by Plate 8, Fig. 5. On the top of each pier a faced cast-iron plate about 12 inches in diameter was levelled and cemented in. The line was taken with a Troughton and Sims 6-inch theodolite; but in summer the object to be observed appeared unsteady, and in both summer and winter there was generally a strong breeze at the crest of the range. The Author took the mean of several observations, from direct observation, and after reversal of the telescope. At the tunnel-end piers a hole was drilled at the point fixed, and a brass pin was tapped into the plate of the same size as the hole in the tripod. The line was checked in the tunnel by fixing 3-inch planks planed on the top and levelled across the heading, and by observing the flame of a short stump of wax candle placed in a turned and bored brass ring. Iron bars were fixed in the roof, and nicks cut and points given; from the iron bars swung hanging frames of wire with candle fixed in a heavy plumb-bob for the working line of miners.

The alignment was successful, as the two points varied but $\frac{7}{8}$ inch when the headings met, the two centres being blown out at one shift, and a hole 12 inches in diameter having been formed in the centre of the heading. The levels of the bench-marks at the working faces near the junction varied only 0·08 foot. When the headings were completed, the sides were trimmed and linings built where necessary. The sections are shown by Plate 8, Figs. 7. Decomposed granite joints were raked out and pointed with cement. All the brickwork of the archways and walls was executed with Amoy brick, a hard and well-burnt red brick, and laid in 3 to 1 cement mortar. The foundations were of cement concrete composed of 5 parts of stone, 3 of sand, and 1 part of cement. The shaft was filled up in the following manner:—The walls were built of fine-punched granite ashlar set in cement, and there is a red brick semicircular four-ring arch in cement mortar; on the top of the arch was a layer of 2 feet 6 inches of cement concrete, then 10 feet of lime cement, and the remainder of the pit was filled up with red earth deposited by a flood which had overtaken the work while the lime concrete was being laid. The water of the reservoir now covers the site of the shaft. The lime of the concrete showed in the fissures of the rock of the tunnel over 50 feet from the shaft, and there is a large growth of stalactites about the brick faces of the shaft filling.

INLET.

The inlet to the tunnel at Tytam is shown by Plate 8, Figs. 6. The water is brought to a circular basin 10 feet in diameter by an 18-inch pipe furnished with a bell-mouthed end; it then flows over a flat stone and falls into a basin, being delivered into the tunnel over a gauge-weir 6 feet wide. This is made of galvanized cast-iron, with a gun-metal edge riveted on. There is a small pit, and an ordinary boiler water-gauge is fixed against the wall. In the pit are the valves of the pipes for emptying the tunnel, outer basin and circular basin; the pit also acts as an overflow, there being a 3-foot by 2-foot drain leading to the bed of the stream.

The whole of the face-work and basins is of white granite, the retaining-walls being of random rock-faced work with a dado of fine-punched ashlar. The walls are stepped to suit the bank-sides. The archway into the tunnel is of very fine-grained white granite, obtained 8 miles from Tytam. The old face was irregular, and considerable difficulty was experienced in making up the bank. A retaining-wall with water-channel is built above the inlet, earth being rammed over the rough boulder formation to form a turfed slope; numerous piles were driven into the disintegrated granite. The inlet retaining-walls were backed with rubble lime concrete; the foundations and basins were of lime concrete 2 feet thick, with rubble stones placed in the centre around the circular basin; the floor of the outer basin was rendered with cement.

OUTLET.

The tunnel outlet at the Wongneichong end (Plate 9, Figs. 8) consists of a fine-punched white granite ashlar face with angle wing-walls. The water from the tunnel comes through a moulded arch, and falls over a 6-foot weir, similar to the one at the Tytam end, on to granite steps into a basin 10 feet square. The wing-walls are of fine-punched ashlar, with sloping stepped coping. At the south side there is a channel and drain to the ravine, and valves are fixed for emptying the tunnel and basin. The hill face was made up true, soiled and turfed, and catchwaters were cut, and channels formed in concrete.

The walls are laid in a similar manner to those at the Tytam end, namely, in lime mortar composed of 1 part of red earth, 1 part to 2 parts of shell lime, and are backed with rubble lime cement; a ⅜-inch half-round pointing in cement, and blacked while half-set, was used.

During the prosecution of the dam and tunnel works, the Chinese and Europeans were constantly attacked by a malignant fever of a malarial type, locally known as Hong-Kong fever. It caused grave anxiety and embarrassment in providing for the continuous prosecution of the work, and tended in no small measure to retard its progress. The general percentage of illness among coolies, especially in summer, was 25 per cent.; at one time, out of six hundred coolies, more than four hundred and twenty were incapable of working, and once all operations outside had to be stopped for ten days in consequence of the heat and sickness.

III. CONDUIT.

A masonry conduit winds along the mountains from the Wongneichong end of the tunnel to the filter-beds and service-reservoir at the Albany Valley. The conduit (Plate 9, Figs. 9 and 10) consists generally of a channel 3 feet wide by 2 feet 6 inches high, the bed being of lime concrete 9 inches thick, the sides of 10 inches of ordinary Canton blue brick when in excavation, and 14 inches of Canton red brick when exposed, laid in lime mortar, and covered with granite slabs 6 inches thick, over which a bed 6 inches thick of lime concrete is laid. The bottom and sides of the conduit are rendered with cement, the first coat being ½ inch thick, composed of 3 parts of sand and 1 part of cement, and a second coat of 1 part of fine sifted sand to 1 of cement.

The conduit is built in level lengths, a drop of some 6 inches being made about every 250 yards. The total length of conduit is 3 miles, and it includes eight aqueducts of more than one span, in one case twenty-one arches, the widest span being 36 feet, several single spans, and culverts 5 feet to 2 feet square. There are altogether ninety-eight bridges and culverts.

The conduit next the outlet is carried across a deep ravine on the tip bank from the tunnel. A cement-concrete arch is constructed down the valley bed, a 6 to 1 cement-concrete floor being laid roughly, following the bed of stream; on this floor walls of rubble are built in cement and mortar, and a 6 to 1 concrete arch is constructed of 12 feet span; the thickness at the crown is 21 inches, tapering to 2 feet at the springing. At the ends retaining-walls are built across the gorge; at the north end the wall is high, and built in cement mortar, strengthened with buttresses. At the south end it is built in lime mortar, the valley being very narrow at that point. The conduit is carried on the top of the stone bank, having red brick sides, and fine-punched granite slabs. The stone tip is covered with 18 inches of earth rammed to the same slope as the stone bank, and is strengthened with wood pickets, and turfed.

The conduit passes through a spur of hill at one place; the cutting was 95 feet deep, through soft decomposed granite. As there was a likelihood of a slip, the conduit was taken through in a red brick tunnel about 150 feet long, 3 feet wide, and 5 feet high, the sides being 18 inches thick, and the arch four rings in cement; traps and covers provide access at the ends. Midway of the conduit the line crosses a ravine called the Wanchai Gap; there a hollow was a convenient site for a small service-reservoir for the east end of the city. A dam wall containing the conduit is built across the valley; the sides of excavations, where in earth, are faced with rubble stone laid in lime mortar, and backed with rubble lime concrete. The depth of water is 25 feet, and the capacity 1;500,000 gallons; the cost, including the diversion of the mountain road, was £3,650. The foundations of all walls, piers, &c., are carried down to the solid ground or rock, and constructed of either lime or cement concrete. The excavation generally was in red earth or clay and decomposed granite. Occasionally rock cuttings occurred; in one case a boulder 50 feet high by 30 feet square was split and overturned in the valley below, the blast being effected by two holes, each about 15 feet deep and 3 inches in diameter, charged with 25 lbs. of dynamite.

The lime mortar is somewhat peculiar. The lime is of sea-shells burnt, and is used as fresh as possible; it is slightly hydraulic, but not very strong. The mortar is made by simply mixing from 1 part to 3 parts of red earth with 1 part of lime. The red earth is found everywhere on the island, and is chosen by the colour and absence of grit, and in fact, by greasiness when wet. The lime and red earth mixed together is generally used fresh. The mixture is very close and sticky, and sets hard with time; it also sets under water, but very slowly. The mortar is improved by the addition of a little cement, which helps to quicken the hardening, especially in water. All the mortar for the service-reservoir and the filter-beds facing was mixed with a small addition of cement.

Lime concrete is made of the same red earth, shell lime and clean broken granite, for particular work broken to $\frac{3}{4}$-inch cubes, and for ordinary foundations to 1-inch to 2-inch cubes; the proportion for any work required to be watertight or particularly strong is 1 part of lime, 1 of red earth, and 3 parts of ½-inch stone; for ordinary foundations it is 1 part of lime, 1 of red earth, and 4 parts of 1-inch stone. This concrete is very close, and sets remarkably hard, both in air and under water, especially sea-water, when not disturbed. The addition of a small quantity of cement, as in the mortar, improves the setting. The granite obtained in Hong-Kong is of very good quality; but care has to be taken that the boulders used are not of coarse granite in process of decomposition. In the valleys about the line of conduit boulders of extremely hard fine-grained basaltic stone, like whinstone in grain, are met with. They are easily split, and ring like an anvil when struck with a hammer. The basalt is too hard to be worked with a chisel; but flat beds can be ensured, and a good rock face by use of a spalling hammer. The walls of half the conduit, and of the filter-beds and service-reservoir, were of this stone.

Retaining-walls were principally built of dry rubble stone, laid, as far as possible, with flat beds, and well keyed up with wedge-stones and spalls; one header at least 12 inches square, of a length of the full thickness of wall, was provided to every square yard of face. All spaces between the walls and excavation were filled up with loose rubble stones hand-packed. The abutments of bridges were built in lime mortar of similar masonry to the dry walls, but with a bed of lime mortar composed of 1 part of lime to 2 parts of red earth. All tops of walls were finished with a coping of fine-punched granite laid in cement mortar, dowels were cut in the cross joints and run in with cement.

Granite beams, 12 to 14 inches square, carried the conduit over spans up to 10 feet, the ends being run 2 feet each end into walling and bedded on corbel stones in cement. Spans of 14 feet were constructed with corbels on the piers, reducing the span to 8 feet.

The numerous ravines and water-courses which cross the line have their beds above and below the road roughly pitched with flat stones laid on lime concrete at least 9 inches thick, and the joints of the pitching were grouted and pointed with cement.

The piers for arches were made of ashlar, which was laid in lime mortar with a small proportion of cement when the height did not exceed 20 feet; otherwise the ashlar was built in cement mortar.

The arches were constructed of granite voussoirs about 12 inches thick; the stones were laid dry on the wood centering, the joints clayed, 2 to 1 cement grout was run in, and chippings were wedged into the cement. The haunches were filled with rubble masonry in lime mortar, or by rubble lime concrete faced with stone. The walls, stonework and brickwork were pointed with cement mortar blackened.

All hillside cuttings have catchwaters excavated above them, about 2 feet 6 inches wide, leading to the culverts or bridge openings. At convenient places along the line pits about 4 feet square and 4 feet deep were constructed in the conduits to intercept sand or silt. Advantage was taken of the construction of the conduit to form a small roadway over it for foot-passengers and chairs only.

The work was begun in January 1885, and completed in May 1887. The total cost, including the Wanchai reservoir supervision, and proportion of office and engineering expenses, was £34,700. Excluding the Wanchai reservoir, the following were the principal quantities and the average prices paid for various classes of work:—

	Cubic Yards.	Average Price per Cubic Yard. £.	s.	d.
Excavation	30,000	0	0	8
Dry rubble walling	11,000	0	8	4
Mortar walling	2,800	0	11	8
Arch masonry	600	2	10	0
Pier "	920	1	3	4
Stone beams	150	1	13	4
Concrete	1,200	0	10	0
Pitching	1,600 sq. yds.	0	1	8 per sq. yd.

The average cost of the conduit alone, including rendering with cement, stone covers, &c., was, when in cutting, 13*s.* per lineal foot, when in red brick 18*s.* per lineal foot. Including all works, roadway, &c., it came to about £10,000 per mile.

IV. FILTER-BEDS AND SERVICE-RESERVOIR.

The filter-beds and service-reservoir (Plate 9, Figs. 11 to 16) are situated at the end of the line at the Albany Valley. There being no level land, the beds had to be cut out of the hillsides. The north wall is an embankment, and the south wall is in cutting over 60 feet deep. There are six beds, each of an average area of 154 square yards; the total area for, say, five beds in operation at once being 2,700 square yards. As the water is only occasionally turbid during the prevalence of heavy rains in summer, the beds can be easily made to pass 1,200 gallons per square yard of surface per day; and as the supply is only designed at present for 2,130,000 gallons, it is reckoned that the filter-beds will be sufficient for the extension of the present reservoir, each bed being capable of dealing with about 650,000 gallons; unless heavy rain continued for some considerable time, the six beds could be used.

The foundations for the walls are laid on hard ground, which in the deepest place was 24 feet from the top of the wall. The foundation blocks are carried up in lime rubble concrete; soft ground was taken out and the space filled up to floor-level with loose rubble stone.

The floor consists of lime concrete 12 inches thick, rammed with wood rammers till set, mats having first been laid on the concrete. By continued ramming a hard surface without cracks was formed sufficiently rough to take rendering. The floor is provided with channels and drains, and the whole is rendered with a first coat of cement mortar ½ inch thick, composed of 3 parts of sand to 1 of cement, and a finishing coat ¼ inch thick of 1 to 1 cement mortar.

The walls are of lime concrete faced with rough squared rubble blue stone bedded in lime mortar, with a small proportion of cement added; the joints were well raked out and pointed with cement and sand in equal proportions. The walls are 7 feet 6 inches high at least from the floor; channels for rain are formed leading to drains.

On the floor are placed two rows of salt-glazed, well-burnt bricks 2 inches thick, laid with top joints about ½ inch open (Plate 9, Fig. 16). On the top of the bricks is a layer of about 9 inches of clean washed broken granite, the pieces being about 1½-inch cube; over this is a layer of about 3 inches of clean, washed, broken stones of about ½-inch cube, and a sprinkling of washed granite chippings about the size of peas, and then a layer of 2 feet 9 inches of sea-sand very thoroughly washed, so as to take away the dust and very fine particles. This gives a depth of water of about 2 feet 3 inches above the top of the sand, and 1 foot from the water to the top of the coping.

The conduit was brought round at the south wall of the beds to the inlet well of the service-reservoir; and a branch from the conduit furnished with a wooden sluice leads to each filter-bed. The water is delivered to a stone trough with a lip about 40 feet long, and falls over on to the sand; broken stone is placed at the edge of the trough so that the water shall not work a groove in the sand. A sheet-iron gauge is fixed at the commencement of the beds to measure the delivery of the water from the conduit.

The clear water is drawn off by a cast-iron collecting main from 10 to 20 inches in diameter; 10-inch branches are fixed at each bed leading from channels in the floor of the beds, and are furnished with sluice-valves. There is also a 10-inch main with connection and valve at each bed with the outlet branch.

A sand-washing pit is constructed near the tramway bridge at the entrance, provided with perforated pipes at the bottom, and a main for the supply of water. A house for an attendant, &c., is built at the entrance to the beds. A drain, 4 feet square in section, under the filter-bed conveys the water from the catchwaters above the excavation to below Garden Road. The clear water and emptying mains lead to the inlet well of the service-reservoir. The well is built of granite ashlar laid in cement mortar, and is divided into a dry and a wet compartment, all the valves being in the dry part. The conduit leads to the wet compartment, and water can be fed to the reservoir without passing through the filters. From the well there is an outlet pipe 18 inches in diameter to the outlet-well pipe, so that water can be supplied to the city without going into the reservoir.

The site for the service-reservoir is the bed of a mountain stream. The bed consisted of a mass of huge granite and blue stone boulders, the hillsides being extremely steep. The design adopted provides a reservoir 150 feet wide, and 30 feet deep, containing 6,000,000 gallons. The stream and flood-water is taken under the reservoir in a culvert 16 feet wide. The culvert is in level lengths with vertical drops to suit the contour of the rock bed (Plate 9, Fig. 13). The north wall foundations are carried down to solid rocky ground, on which is deposited a layer of 2 feet of cement concrete. The foundation block is 19 feet wide of rubble concrete; the depth of the foundation in the centre of the dam was 30 feet 6 inches below the bottom of the reservoir, or 61 feet 6 inches from the top of the coping. On the foundation block is erected the dam wall, 15 feet thick at the bottom of the bank, and battering towards the inside of the tank 1 in 3, the north side being vertical. The face is built of rough squared rubble of blue stone set in lime mortar with a little cement added; a skin of lime concrete 3 feet thick is laid against the stone face, and the rest of the mass is in similar concrete but with rubble stones up to 5 cubic feet embedded. The back of the dam wall is lined with 2 feet of loose rubble stones, so that any leakage could be led away into the culvert without touching the earth bank. The lime concrete made a very tight and dense mixture, and the dam wall is perfectly watertight.

The excavation from the reservoir was tipped outside of the dam wall, and, as all the earth was carried by coolies in baskets, the continual traffic made a hard bank. This was relied on to strengthen the dam wall, which alone had not much margin of safety. The end of the culvert formed an abutment for the bank tip, and also made the bridge for the Garden Road to cross the ravine.

The side walls of the bank against the excavations are of similar construction to the dam wall, and are battered at the face 1 in 3, the top thickness being 4 feet and the base 5 feet. The backing to the stone face is of lime concrete, rubble stones being embedded, but no stones were allowed within 1 foot of the back of the stone face. After completion all the joints of the walls were well raked out, and flat pointed with 1 to 1 cement and sand. Spaces between the culvert and solid ground were filled in with loose rubble stones, and grouted with liquid lime and red earth mixed to a thick paste. The bottom floor consists of a thickness of 18 inches of rubble lime concrete and 12 inches of lime concrete; the surface was continually rammed till hard. This took about three weeks, and then a coating of $\frac{3}{4}$ inch of 3 to 1 cement mortar was floated over the surface, which was finished with $\frac{1}{4}$ inch of cement and sand in equal proportions. The archway of the culvert, where exposed in the reservoir, is covered with lime concrete, and rendered in a similar manner. Some springs were met with in the bottom, and conducted by piping under the floor to the culvert.

The inlet into the culvert for the flood-water and stream is formed with wing-walls, and a strong grating of rolled steel joists and 24-lb. rails was built across the opening, which is 24 feet wide. A coping of granite, laid in cement, formed the sill over which the water dropped 32 feet into the culvert on heavy stone pitching laid in cement mortar on 18 inches of cement concrete. During a deluge of rain, in May 1889, a large tip of earth, which had been allowed to exist unprotected from weather, and with insufficient toe walls, at the Peak about 1,200 feet above the reservoir, slipped, and about 25,000 cubic yards of earth fell down the ravine, dragging with it about 200 yards of the Peak tramway, and all the debris, accompanied by granite boulders of over 200 tons weight, came to the service-reservoir. The iron grating was speedily choked, and the inlet and culvert were blocked; the water and silt consequently filled up the reservoir and overflowed the dam wall to a depth of 4 inches, carrying away all the outer bank, and leaving the water pouring in a cascade over the north wall. None of the masonry nor concrete work failed under the enormous strain so suddenly thrown thereon. The outlet-well is built of granite ashlar backed with lime concrete, and contains the 18-inch supply-main and 10-inch wash-out, with the connections to the by-passes from the inlet-wells; suitable valves control the supply. The pipes are carried under the bank in a tunnel formed of masonry walls and granite cover-stones. The 18-inch supply-pipe continues down the Garden Road into the city; the 10-inch emptying pipe delivers into the stream at the culvert bridge.

The Garden Road was diverted and an entrance made, and a new road is formed at the toe of the filter and reservoir bank. Two wing-walls of dry rubble stone were constructed on each side of the ravine about 40 feet high. An apron in front of the bridge, carried down to solid rock, and covered with strong pitching laid in cement, was uninjured when the water, flowing over the bank, carried away the wing-walls and pitching of the ravine.

The cost of the filter-beds, including supervision, proportion of office and engineering expenses, coolie quarters, &c., was £8,043 for an area of 3,246 square yards of filtering-surface, which is equal to £2 9*s.* 6*d.* per square yard. The cost of the service-reservoir, including supervision, office and engineering expenses, was £13,052.

The cost of the diversion of the road, and making the new branch of Garden Road, was £1,666, raising the total to £22,761 for the whole work. The principal quantities of the filters and reservoir and the average prices paid were—

		Cubic Yards.	Average Price per Cubic Yard.			
			£.	*s.*	*d.*	
Earth excavation	about	88,000	0	0	8	
Rock „	„	8,500	0	3	4	
Dry rubble walling	„	3,000	0	5	0	
Mortar „ „		2,200	0	8	4	
Cement concrete	„	650	0	10	0	without cement.
Rubble and ordinary lime concrete		2,600	0	5	10	
„ „ fine „ „		9,000	0	7	6	
Fine lime concrete		4,000	0	8	4	
Ashlar in arches with centres, &c.		405	2	10	0	
„ side walls of culvert in cement		1,000	0	10	0	
Rubble stone facing of walls		1,500	0	8	4	
Dry stone filling grouted		3,100	0	3	4	
Broken stone for filters	about	1,600	0	2	4	
Sand for filters	„	4,000	0	2	4	
Cement		3,200 barrels	0	13	4	each.
Turfing		10,000 sq. yds.	0	0	6	per sq. yd.

The total cost of the Tytam Water-Works as described was:—

		£.
I.	Reservoir at Tytam	99,168
II.	Tunnel	52,950
III.	Conduit	34,700
IV.	Filters and service-reservoir	22,761
	Total	£209,579

As all local payments are made in Mexican dollars, the value for labour and materials is difficult to estimate, owing to fluctuations of exchange; the government rate is 4*s.* 2*d.* per dollar. Five years ago the value was about 3*s.* 8*d.*, at present it is about 3*s.* The Author has taken an assumed value of 3*s.* 4*d.*

The Paper is accompanied by two sheets of tracings, from which Plates 8 and 9 have been engraved.

[APPENDIXES.

APPENDIXES.

APPENDIX I.—Dimensions and Cost of Reservoir and Dam.

Height of top water-level above mean sea-level	feet	496·30
„ from foundation to top of dam	„	120
„ „ lowest water-level in reservoir to top of dam	„	109
Available depth of water for supply	„	93
Length of dam between hillsides	„	562
„ „ „ end walls	„	485
Drainage area	acres	700
Area of reservoir	„	27
Contents of reservoir	gallons	310,000,000
Thickness of dam at present top level	feet	23½
„ „ bottom of dam wall	„	62½
„ „ base of foundation block	„	76½
Length of by-wash (clear waterway)	„	100
Greatest observed depth of flood over sill	„	4
Depth of sill of by-wash below top of dam	„	2
Least supply of water per day during dry season	gallons	2,130,000

Quantities.	Cubic Yards.	Approximate Cost per Cubic Yard. £	s.	d.
Ashlar masonry, inner face and valve-well	1,802	1	14	2
Granite coping	478	2	16	0
Rubble walling, outer face	1,863	0	8	0
„ concrete	41,491	0	16	8
Fine „	11,317	1	5	0
Extra fine concrete	9,346	1	10	0

Making a total mass of 66,297 cubic yards in the dam and foundations at an average cost of £1 2*s.* per cubic yard.

Cost of Reservoir.

	£
Dam concrete work, including preparing foundations, cement, &c.	68,213
„ masonry, inner and outer face and valve-well	4,940
Supervision and quarters	7,370
Valve-well and scour-valve, ironwork and erection	2,353
Excavating foundations, making roads, and completing works	8,391
Reservoir lining against inner face of dam	3,663
By-wash	4,238
Total cost of reservoir	£99,168

APPENDIX II.—Dimensions and Cost of Tunnel.

Length of tunnel	yards	2,428
Height of floor above mean sea-level	feet	400
Greatest height of ground above tunnel floor	„	950
Average size of tunnel	„	by 7½

Particulars of Cost.	Total.	Per Lineal Yard.		
	£.	£	s.	d.
Cost of machinery, drills, including—				
Freight, transport and erection	9,922	4	1	9
Tools and materials bought locally	1,371	0	11	3
Repairs to plant done locally	1,217	0	10	0
European mining supervision	7,806	3	4	4
General and office expenses, proportion of—				
Consulting and Resident Engineers' expenses	1,602	0	13	2
Chinese labour inside tunnel	5,463	2	5	0
„ „ outside „ (stokers, engineers, &c.)	3,276	1	7	0
Explosives, 62,395 lbs.	6,277	2	11	9
Fuse 16,062 coils	803	0	6	7
Caps 123,150	205	0	1	8
Coal 5,406 tons	8,903	3	13	4
Oil, candles, and waste	1,424	0	11	9
Cost of boring tunnel	£48,269	£19	17	7
Lining tunnel	2,057			
Shaft	591			
Inlet basin and works	1,993			
Outlet „ „	1,040			
Total cost of tunnel, &c.	£53,950			

APPENDIX III.—ROUGH COMPARATIVE TESTS of 1½-INCH by 1½-INCH BRIQUETTES of VARIOUS MIXTURES.

Amount of water used for mixing from 19 to 22 per cent.; sand, lime, and red earth sifted through a 800 sieve; lime was of common sea-shells burnt and used fresh; English Portland cement supplied through the Crown agents for the Colonies; wet briquettes placed in water as soon as set; Michele's tester used; the red earth was free from sand and grit.

Mixtures.				Tensile Strength in Lbs. per Square Inch.					
Cement.	Lime.	Red Earth.	Sand.	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.
				One Month.		Four Months.		Six Months.	
1	..	..	..	610	720	..	..	1,230	1,340
..	1	..	..	..	..	..	..	141	94
1	1	..	..	..	..	780	520	690	750
1	3	..	..	..	..	480	310	460	440
				Two Months.					
3	1	..	..	..	..	870	870	960	910
1	..	3	..	253	320	400	350	440	410
3	..	1	..	..	..	990	850	1,140	1,210
1	..	..	3	640	630	750	710	800	710
1	..	..	1	730	680	..	..	1,220	1,160[1]
1	..	1	..	513	600	830	670	1,105	880[2]
..	1	..	1	0	0	103	0	190	0[3]
..	1	1	..	180	173	209	336	270	354
..	3	..	1	..	..	..	..	300	0[3]
..	3	1	..	..	..	263	309	293	374
3	..	..	1	..	..	..	..	1,480	1,300
1	1	..	1	..	..	300	290	790	770
1	1	1	..	..	..	640	542	580	570
1	3	..	1	..	..	..	..	300	420
1	3	1	..	..	..	470	372	460	420
2	1	..	1	..	..	..	..	1,120	980
2	1	1	..	..	..	..	..	810	760

[1] The fractured portion showed damp.

[2] The fractured portion showed dry.

[3] The briquettes laid in water would bear no strain, but crumbled to pieces.

(*Paper No. 2441.*)

"The Construction of the Yokohama Water-Works."

By JOHN HENRY TUDSBERY TURNER, B.Sc., Assoc. M. Inst. C.E.

THE works for the water-supply of Yokohama were completed in October 1887.

This, the first introduction of the European system of water-supply and distribution into Japan, has naturally been regarded by the Japanese public as a crucial test of the efficacy of this phase of sanitary reform in the peculiar climatic and other conditions that prevail there.

The town of Yokohama occupies an alluvial flat at the head of one of the arms of the Gulf of Yedo. It is flanked by two ranges of hills, on which stand the suburbs. The western of these, Nogeyama, rises to about 165 feet above mean sea-level, and afforded a favourable site for a service-reservoir within a mile of the centre of the town.

The population, including that of the suburbs, is, according to the latest return, one hundred and eighteen thousand nine hundred and forty-seven. In common with all other Japanese towns the houses are built of timber, to which circumstance must be attributed the frequent occurrence of fires during the dry winter season.

Previously to the introduction of the new supply of water, the population drew all water for domestic purposes from shallow wells sunk in the gravelly sub-soil of the town, and, owing to the absence of a good drainage system, these wells were extensively polluted by the infiltration of water already fouled by use.

The attention of the municipal authorities was forcibly directed to this insanitary state of affairs by recurrent epidemics of cholera during the last twenty years; and an official investigation, conducted by the late Dr. Geerts,[1] proved that a close relation existed between the use of the water from polluted wells and the virulent development of choleraic disease. Under these circumstances it was decided to introduce a high-pressure water-supply for the service of the town proper, the population of which was estimated to be between seventy thousand and eighty thousand.

In the early part of 1883 the Japanese Government, with the assent of Her Majesty's Government, requested Colonel (now

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[1] Proceedings of the Asiatic Society of Japan. Vol. vii. part 3.

Major-General) H. S. Palmer, R.E., Assoc. Inst. C.E., who was at that time spending a short vacation in Japan, to prepare a design for the execution of the project; and this subsequently led to the lending of Colonel Palmer's services to the Japanese Government from the beginning of 1885, as Engineer during the construction of the works.

The question of water-supply to Yokohama involved considerations of a somewhat exceptional character. In the first place, the works had to be constructed in a district subject to earthquakes, some of them of extreme violence. Secondly, the daily volume of water to be provided had to be estimated for a population whose domestic habits are peculiar to the Japanese people. Thirdly, it was difficult, and often impossible, to obtain information about such matters as rainfall, evaporation, and the applicability of native materials to new kinds of construction.

After an exhaustive inquiry, Colonel Palmer reported in favour of a gravitation supply from the Sagami River, at a point about 28 miles distant from Yokohama. This scheme was approved by the Government, and operations were commenced in April, 1885.

Houses for the accommodation of the engineering staff were built at three points on the line of the aqueduct, and were connected by telephone with the head office at Yokohama. A light "Decauville" tramway of ½-metre gauge was provided along the line of works, for the conveyance of materials and stores.

SOURCE OF SUPPLY.

The River Sagami rises on the north-east flank of Fujiyama, and enters the sea near Fujisawa on the Tokiado, after a course of about 60 miles. For the first 40 miles the river runs in a deep and rocky channel through the metamorphic rocks of the Oyama range. The sparsely populated watershed yields a clear, soft water of exceptional purity. The late Dr. Geerts ascertained its composition to be as follows:—

	Parts in 100,000.
Silicic acid	2·20
Oxide of iron	trace
Alumina	0·55
Chlorine	0·33
Calcium oxide	0·95
H_2SO_4 as sulphate	0·30
HNO_3 as nitrate	0·023
Ammonia	0·0054
Albumenoid ammonia	0·015

Hardness . . 2·5 English degrees.

The river is subject to floods at certain seasons, the vertical variation of water-level at the point of intake amounting sometimes to 20 feet. High floods bear down a considerable quantity of silt in suspension, but they are always of short duration, and the water seldom retains its turbidity for a longer period than three days. The ordinary dry-weather flow of the river is, according to the Author's gaugings, about 529,000,000 gallons per day.

Intake Works and Pumping-Station.

These are situated at Mii-mura, on the left bank of the River Sagami, at about 35 miles from its source. The lowest known water-level of the river at the point of intake is 353·70 feet above mean sea-level at Yokohama.

The choice of a site for the pumping-station was somewhat restricted by the nature of the ground, and it was considered desirable to carry the intake works a short distance higher up the river.

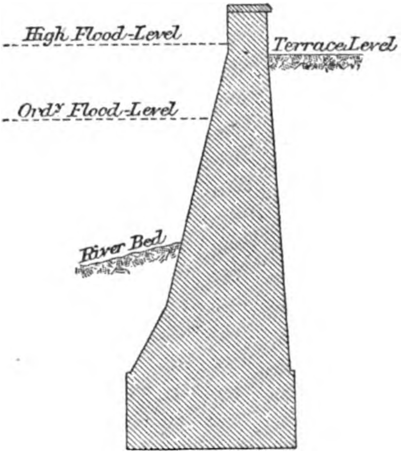
The intake, commencing about 200 yards up-stream, consists of a duplicate 18-inch cast-iron main pipe laid horizontally in a trench excavated out of the rock below the lowest water-level. The pipes are flanged and bolted together. The inlet ends of the mains are carried through a low concrete wall facing up-stream, and are furnished with screw-valves and wire-gauge strainers on the outside. An iron column surmounted by a platform stands upon the wall, and is secured by tie-rods to the adjacent cliff. A light iron gangway affords access from a pathway, cut in the cliff, to the platform, from which the inlet-valves and strainers are manipulated. A heavy concrete breast-wall is constructed in front of the above-mentioned work to protect it in high floods, and is carried up to a level of 3 feet above the valves. The 18-inch intake-mains lead into a brick connecting-pit provided with a massive stone cover, and placed clear of the retaining wall of the pumping-station. From this well the pipes are carried through the retaining wall into a brick suction-well of 10 feet diameter.

The engine- and boiler-houses are built upon a terrace, formed behind a concrete retaining wall (*Fig.* 2), which is surmounted by a brick parapet wall 2 feet high.

The pumping-machinery consists of a pair of horizontal compound-engines with surface-condensers. The main pumps are double-acting piston-pumps of 16 inches diameter and 27 inches stroke, with rubber disk-valves working on cast-iron seats. They are actuated by the tail-rods of the low-pressure cylinders. The air-pumps are worked from the tail-rods of the high-pressure cylinders. The suction-pipes are 14 inches in diameter, and are furnished with footvalves at the bottom of the suction-well, which is situated 8 feet from the wall of the engine-house. The delivery is by duplicate cast-iron main 14 inches in diameter, and is carried underground from the air-vessel in the engine-house up to the level of the depositing-tank, into which the pipes deliver.

The boiler-house contains three Cornish boilers 14 feet long and 4 feet 6 inches in diameter, with space for a fourth boiler should it be required. The chimney is built clear of the boiler-house wall, so as to allow it freedom of oscillation in earthquakes.

Fig. 2.



Scale 10 feet = 1 inch.

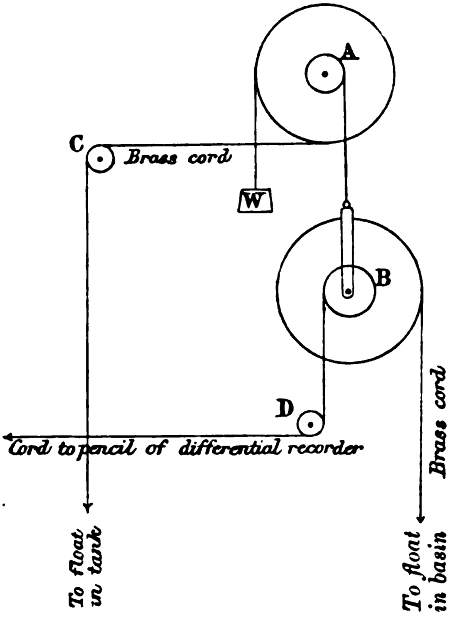
The water-level in the depositing-tank is 54 feet above the lowest level of the river, and each engine is capable of raising 1,250 gallons per minute through the full lift.

The depositing-tank is 210 feet long, 8 feet wide, and 6 feet deep. A partition wall carrying a gauge-plate is built across the tank at 10 feet from the lower end, forming a basin, which is provided with an overflow. The tank is constructed on a benching cut out of the rock on the mountain side. The floor is of concrete laid upon puddle-clay; the walls are brickwork backed by puddle as high as the water-level. Two sluice-valves are provided at the floor-level for cleansing the tank.

The gauge, through which the water passes from the depositing-tank to the basin, is a submerged vertical rectangular orifice 2 feet long by 6 inches high, with squared brass lips $\frac{1}{4}$ inch thick, placed 2 feet 6 inches below the surface of the tank. The head of water above the orifice is measured by an automatic apparatus, consisting of two copper floats, immersed in the water at the upper and lower sides of the orifice respectively, which actuate a differential recorder and an integrator fixed in a gauge-house at the side of the tank. The discharge through the orifice is dependent upon the head due to the difference of water-level on the upper and lower sides of the gauge, which difference is recorded by means of the floats.

The relative motion of the floats is reduced to one-third for the differential recorder, which is of the revolving disk form.

Fig. 3.



The arrangement of pulleys by which the recording pencil is actuated solely by the relative water-levels on the two sides of the orifice, without reference to the actual water-levels, is shown by *Fig. 3.* The diameters of the double pulley A, which turns on a fixed axle, are 4 to 1; those of the double pulley B, which turns on an axle suspended from A, are 3 to 1. C and D are fixed guiding pulleys. W is a weight hung on the end of the continuous cord from the upper float round C and A.

The discharge through the orifice, under the actual conditions of working, was ascertained by experiment, and found to be very accurately expressed by the formula :—

$$Q = 2{,}000 \sqrt{h}.$$

Where Q denotes gallons discharged per minute; and *h* denotes the head of water in feet, namely, the difference of level between the surface of the water on the inlet and outlet sides of the gauge.

This completes the description of the works connected with the intake at Mii-mura.

The remoteness of the place rendered it necessary for permanent quarters to be constructed for the accommodation of the engine-men and coolies. These do not, however, need special remark.

The performance of the engines has been very satisfactory since the works were opened, their normal rate of running being 32 revolutions per minute.

Portland cement was used for the concrete and mortar. Stone, gravel, and sand were obtained from the bed of the river, and before being used were well washed in troughs, erected in the river for the purpose. A brick-yard was opened at a place about 8 miles down the river, for supplying the necessary bricks to the intake works and the upper portion of the aqueduct. The bricks, as well as the engines, boilers, pipes, valves, and all plant and stores, were dragged up the rapids of the Sagami-gawa to the works, for a distance of 6 miles, in flat-bottomed boats; an undertaking that in itself reflects in no small degree upon the perseverance and skill of the men engaged upon this part of the works.

AQUEDUCT.

The total length of the aqueduct, from the intake works at Mii-mura to the filter-beds and service-reservoir on Nogeyama, is 27 miles.

The hydraulic gradient of the first 18 miles, to the summit of the Katabira-gawa watershed, is 6 feet per mile. At this point the diameter of the main pipe is reduced from 18 inches to 15½ inches, and the hydraulic gradient of the remaining 9 miles is 14 feet per mile. A section of the entire line is given in Plate 10, Fig. 1.

Commencing at the basin below the gauge at Mii-mura, the aqueduct follows the left side of the deep cañon of the River Sagami for a distance of 7 miles; and consists of alternate sections of 18-inch cast-iron pipes and of short conduit tunnels, which pierce the more projecting spurs of rock that abut upon the river.

In five cases tunnels were driven at levels below the hydraulic gradient for the reception of the main pipe. The tunnels on the hydraulic gradient are sixteen in number. All are 4 feet 6 inches by 4 feet 3 inches in cross section, and are generally unlined, the bottom being roughly dressed with the pick. In a few places, where the rock was unsound or the tunnels were cut into the gravel beds that mark the margin of the river at its ancient levels, brick-in-cement lining was resorted to. Small brick-lined wells, sunk below the floor-level, were constructed at the upper and the lower ends of every conduit-tunnel. The intermediate sections of main pipe were connected with these wells, and governed by valves on the lower extremities of the sections. The wells were provided with sluices and overflows.

As a preliminary to laying the main pipe in this upper portion of the aqueduct, a road, following where possible the hydraulic gradient, and wide enough to carry the tramway and a row of pipes alongside, was constructed by cutting a benching along the precipitous wall of the river. The driving of the tunnels was proceeded with at the same time; for which work dynamite was extensively used, the drilling being done by hand.

When the road was finished the "Decauville" tramway was laid down, and the pipes were transported along it, through the tunnels, to their places. The pipes were laid in a trench for the most part hewn out of the rock along the inner side of the roadway. The sinuous course of this part of the pipe-line necessitated the introduction of an unusual number of special bend-pipes and of short straight lengths. For this purpose an accurate survey of the route was made to a large scale, upon which the bends were marked. They were reduced to typical classes, namely, 25 feet radius, 50 feet radius, 30°, 45°, 60°, and 90° bends, and the trench was set out to suit these types. The quick bends were formed with the bend near the socket end, and had straight spigot ends to facilitate jointing.

At Oshima, where the aqueduct issues from the Sagami defile, the main pipe diverges from the river, and runs direct to the summit of the Katabira-gawa watershed.

With the exception of the inverted siphons through one or two ravines that cross the route, the pipe-line on this section presents no feature of special interest. The work of transport and pipe-laying was easy and rapid; the only difficulty encountered being to secure adequate fall in the main pipe for cleansing purposes.

At Kami-Kawai the 18-inch main pipe delivers into an elliptical brick well, surrounded by and seated upon puddle. The well was constructed as a relief-tank for the main pipe between this summit and the service-reservoir on Nogeyama.

This last portion of the main pipe which, as already mentioned, is 15½ inches in diameter, follows the bottom of the Katabira-gawa valley for a distance of 8 miles, and in its course traverses a long stretch of low-lying land, some 280 feet below the summit-level at Kami-Kawai. The 15½-inch main pipe crosses the Katabira-gawa at thirteen places, and is carried on strongly-framed timber bridges, built of the durable Keyaki (*Zelkova Keaki*);[1] except at one crossing, where circumstances necessitated the erection of a steel lattice-bridge of 70-feet span, carried upon concrete and pile abutments. Stop-valves, with sluices on each side of them, were inserted at intervals of about 2 miles throughout the pipe-line. Automatic air-valves were placed at all summits, and sluice-valves at all hollows.

The 18-inch main pipes are 11/16 inch in thickness, the 15½-inch pipes being likewise 11/16 inch thick, as they are subject to a higher pressure. They are jointed with yarn and lead, the depth of lead being 2 inches, and the average thickness of the joint ⅜ inch.

The actual quantity of lead used in jointing the pipes was, for 18-inch pipes, 20·8 lbs. per joint; and for 15½-inch pipes, 18·7 lbs. per joint. General Palmer's experience of construction in earthquake countries convinced him of the superiority of this joint, in the circumstances, over that of a turned and bored joint; to the employment of which many portions of the pipe-line were otherwise favourable. The river crossings were, however, laid with flange-joints.

The stop-valves and sluice-valves are double-faced screw-valves with gun-metal faces—the sluice-valves being 4 inches in diameter. The air-valves are of the gutta-percha ball pattern. The 18-inch pipes were tested to a pressure of 150 lbs. per square inch, and the 15½-inch pipes to 170 lbs. per square inch, before leaving the maker's hands; and the valves were tested to a pressure of 200 lbs. on the square inch. Wrought-iron rings, 1 inch by ⅝ inch, were shrunk on the spigots of the pipes before shipment; a precaution that resulted most satisfactorily, in the avoidance of breakage during transport.

All ironwork was minutely inspected on its delivery in Japan. Fractured pipes were cut and used whenever possible. Suspicious cases were at once tested under hydrostatic pressure.

Where the main pipe was intended to sustain the greatest

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxix. p. 417.

working pressure, it was, as soon as laid and jointed, charged and subjected to a pressure exceeding the working pressure at that place. This was done before the pipe-trench was completely filled in, when any faults were at once seen and remedied. Some difficulty was experienced with the lead joints, owing to the expansion and contraction of the pipes caused by the great range of daily temperature. But, by screening the pipes from the direct rays of the sun during caulking, and covering the barrels with earth as soon as possible after the pipes were laid, the difficulty was overcome.

SERVICE-RESERVOIR AND FILTERS AT NOGEYAMA.

The general plan of this part of the works is shown by Plate 10, Fig. 2, which also gives the contours of the site.

The 15½-inch main pipe from Kami-Kawai delivers into a circular brick well encased in puddle, Figs. 3 and 4, which is situated at the north-west angle of the filter-beds. This well is provided with an overflow and wash-out, from which an 8-inch waste-water pipe is laid to discharge into a neighbouring watercourse. From the valve-well an 18-inch cast-iron supply-pipe, furnished with an automatic valve, to prevent loss of water from the filters in the event of a sudden burst in the main pipe, runs along the west side of the filter-beds, to which it connects by 13-inch branch inlet-pipes, commanded by separate valves.

The filter-beds, Fig. 2, are three in number; two are ordinarily in use together whilst the third is being cleansed. Each bed is 120 feet long and 70·5 feet wide. They are constructed of concrete, bedded upon and backed by puddle, with ashlar facing above the level of the sand; the walls are surmounted by dressed stone copings. The thickness of the filtering sand is 2 feet 6 inches, and the ordinary depth of water over it is 3 feet. Underlying the sand is a layer of gravel 6 inches in thickness, composed of four beds of varying degrees of fineness. This is, in turn, supported by two layers of bricks arranged to form a series of covered parallel drains across the floors of the filter-beds.

A main longitudinal drain, 1 foot 6 inches by 1 foot 3 inches in cross section, runs from end to end of each filter-bed. The transverse brick drains deliver into this main drain, which is provided at its upper end with a 4-inch ventilating pipe, recessed into the end wall; and at the lower end it communicates with a sump, from which a 13-inch pipe, provided with a ventilating pipe, is laid through the concrete wall, and forms the outlet for the filtered water.

The details of the main drain, ventilating pipe, sump and outlet are shown by Figs. 5 and 6; also those of the 13-inch inlet pipes previously mentioned. The inlets deliver on the surface of the filtering sand, through up-turned horizontal bell-mouths, recessed into flags 3 feet square, which spread the incoming water.

The filtered-water outlet-pipes connect with an 18-inch pipe, Fig. 2, laid towards the service-reservoir for some distance parallel to the 18-inch supply-pipe, and connected with it in such a way as to allow of its being used as a by-pass. This pipe delivers the filtered water into the inlet-well of the service-reservoir.

The service-reservoir is 190 feet long by 144 feet wide, and overflows at 18 feet depth of water. The top-water level is 2 feet 6 inches below the coping. It is, like the filters, built of concrete encased in puddle up to the water-line. The walls batter 1 in 12 on the inside, and are faced with brickwork toothed into the concrete backing, Figs. 7, 8 and 9. Two circular brick wells 8 feet in diameter are built behind the north wall of the reservoir. Into one of these, the inlet-well, the filtered-water pipe delivers through a vertical telescopic pipe, the upper length of which slides within the lower length, and can be raised or lowered by means of a capstan wheel, and adjusted so as to give with precision the head of water under which it is desired to work the filters. The reservoir overflow pipe is also placed at one side of the inlet-well.

The reservoir is supplied by an 18-inch pipe, passing from the bottom of the inlet-well through the walls, and delivering through an upturned bell-mouth 3 feet above the floor.

The draw-off pipe, which is provided with a cast-iron strainer, passes from the bottom of the reservoir through the walls into the second of the wells mentioned above. This, the outlet-well, Fig. 9, contains a valve commanding the 18-inch supply-main to the town, the head of which is fixed in the well, near the bottom.

The two wells are connected by an 18-inch by-pass pipe, controlled by a valve in the outlet-well. This by-pass can be used when the reservoir is being scoured; or if, in the event of a serious conflagration, it should be desired to pass unfiltered water direct to the town.

The above two wells are shown by Figs. 8 and 9, and the 8-inch reservoir wash-out-pipe is shown by Fig. 7. This wash-out and the overflow-pipe from the inlet-well deliver into a circular brick-well 4 feet in diameter, from which a stone culvert is carried to the watercourse close by.

Every precaution was taken to ensure the stability and proper execution of every part of the works connected with the reservoir and filter-beds. The selection and manipulation of the puddle clay, upon which it was felt the water-tightness of the structures would probably depend entirely, was directed with the greatest care. A satisfactory clay was procured from Yokosuka, about 12 miles distant from Yokohama. It was thoroughly aerated and disintegrated by frost during the winter before it was used. It was then cut, watered, and trodden four times *in situ*.

In order to prevent unequal settlement, the puddle under the walls of the reservoir was stiffened by an admixture of river ballast in the proportion of 4 parts of clay to 1 part of ballast. And in constructing the concrete works, the walls were first raised 10 feet above the footings, and then the concrete floor was laid simultaneously with the completion of the walls. The puddle and earth backing were also carried up behind the walls simultaneously. The brick facing was Flemish bond on the face, and every third course was toothed into the concrete work behind.

Where pipes were laid through the walls, they were first built in up to the level of the pipe barrels. Arches were turned over them, and on completion of the works, the arches were filled up solid with concrete and brickwork. All fractures from settlement were thus successfully provided against.

The Portland cement for the concrete and mortar was imported from England, and before being accepted was subjected to a tensile-stress of 430 lbs. on the square inch seven days after moulding. It is due to the makers to mention that the average breaking-strength of the cement proved to be considerably higher than this, the contract figure. The proportions of the materials used for the concrete, which were arrived at by trial, were as follow: 9 parts broken stones 2 inches to 3½ inches in diameter, 1·6 part gravel less than 1 inch in diameter, 1·6 part sharp sand, and 1 part Portland cement. This produced, when mixed, an exceedingly compact concrete, the net proportion of matrix to aggregate being nearly 1 to 9. For mortar 1 part of Portland cement was mixed with 2 parts of sand.

As building had to be carried on through the heat of the summer of 1886, straw screens were erected to protect the work in progress from the direct action of the sun's rays, which threatened to impair the setting of the concrete and mortar by rapid evaporation of the water.

The outside earth slopes of the reservoir and filter-beds, which are half excavated and half embanked structures, were turfed as soon as possible after they were finished, in order to protect them from the action of the heavy rains that accompany typhoons.

With regard to the reservoir, experience in working has shown that, notwithstanding its considerable depth of 18 feet, it is necessary to exclude the light from the filtered water. A roof, carried on iron columns, has therefore been added to the reservoir; the floor of which was made strong enough originally to carry such a roof if required, its construction being withheld from motives of economy until its necessity should be established.

DISTRIBUTION TO THE TOWN.

An 18-inch main-pipe is laid from the outlet-well of the service-reservoir down the hill to the centre of the town. The distribution is effected through a ramification of 8-inch and 4-inch pipes branching off the main, each main branch being under the control of a meter.

The entire area of supply is placed under the control of the waste-water meter invented by Mr. G. F. Deacon, M. Inst. C.E.[1] The town is divided into thirty-one districts, and each district is supplied through a meter placed on a by-pass pipe at the main branch. The service-pipes of the various districts are joined at suitable points, so as to allow of rapid draught in case of fire. The junctions are closed by stop-cocks when the districts are being specially examined for waste.

The Japanese portion of the town, comprising five-sixths of the whole, is in general supplied by "stand-pipes" or "street fountains," placed at every 300 feet along the streets. This course was adopted owing to the inflammable and perishable character of the poorer class of Japanese houses. But in the better quarters of the town, where the more durable character of the houses warranted it, water-service was laid on to the houses upon the requisition of the occupants. Midway between the street fountains, and therefore at every 300 feet apart, ball fire-hydrants were fixed. The remaining portion of the town, called the Foreign Settlement, was, owing to the superior style of the buildings, not supplied by street fountains, but by lead service-pipes laid into the houses; fire-hydrants being distributed throughout the area as in the rest of the town.

Water for manufactories and tea-firing establishments is supplied through "Siemens" meters. Water for ships is also sold by measure; otherwise the water revenue is raised by rates on assessed rental. The average cost of the water is about 9*d.* per 1,000 gallons.

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[1] Minutes of Proceedings Inst. C.E., vol. xlii. p. 143.

A small fire rate is payable by the Japanese. The use of water for gardens, cattle, and carriages entails a small extra charge. The service is constant, and the pressure in the main pipes is between 60 and 70 lbs. on the square inch.

Since the works were completed in October 1887, the greatest success has attended the undertaking, both financially and as regards absence of failures of any kind. The whole cost was about £177,000.

The care bestowed upon the pipe-laying and jointing enabled the main to be brought into regular work at once, only two fractures appearing when the full pressure was laid on. The absence of leakage from the several tanks, and filter-beds, and the service-reservoir, notwithstanding several severe earthquakes and a multitude of smaller shocks, demonstrates the efficacy of good puddle properly worked, in earthquake countries.

Praise is due to the entire body of the junior engineering staff engaged upon the works for the zeal and intelligence they displayed in work that was new to them in almost every respect.

The pipes were supplied by Messrs. Laidlaw and Son, the cement by Messrs. White and Co., the pumping machinery by Messrs. Hathorn, Davey and Co., and the valves, hydrants, and other accessories by Messrs. Blakeborough and Co. Mr. W. Hope, Assoc. Inst. C.E., acted as Government Agent in England, and Mr. F. Walkinshaw joined the staff as Mechanical Engineer in July, 1887.

The Author acted as Chief Assistant Engineer during the construction of the works, and presents this brief account of them to the Institution, with the kind concurrence of Major-General H. S. Palmer, the Engineer, whose engagements in Japan at present occupy his undivided attention.

The Paper is accompanied by several drawings and tracings, from which Plate 10 and the *Figs.* in the text have been prepared.

[DISCUSSION.

Discussion.

Mr. Hart. Mr. J. W. HART said it appeared upon the plan accompanying his Paper (Plate 7, Fig. 3), that there were certain filter-beds for future extensions. Those extensions had been partly carried out. It was also stated in the Paper that provision had been made for the cost of extensions and additional pumping-engines and boilers. Those pumping-engines and boilers were now in the course of construction, and the engines would pump 200,000 gallons per hour into the water-tower. The available space for the additional engines and boilers was therefore being occupied, and the additional capital stated as likely to be required would be called into use by the extensions which were being carried out.

Mr. Orange. Mr. ORANGE desired to read an extract from a letter written to Sir Robert Rawlinson by Mr. Osbert Chadwick with reference to the Tytam reservoir. He had made an examination of the dam, especially to see what damage had occurred from a great rainfall at Hong-Kong, in May 1889, when 27½ inches of rain fell in twenty-four hours, and 3·4 inches in one hour; and he stated in his letter:—"I have made a careful inspection of Tytam. The heavy rains did no damage to the structure. Some of the ornamental slopes of made ground were washed down, that is all. The by-wash was abundantly large. The water poured over it upwards of 4 feet deep, being at the rate of 5 inches of rain flowing off the area per hour. The work looks excellent. The masonry only shows a few weeps, which are evidently taken up. There is, however, a considerable leakage at the flanks through the solid ground, and some springs show themselves in the valley below the dam. They may to some extent be natural. All the water from these leaks comes out brilliantly clear, only depositing some irony matter. In short the dam is perfectly tight, no water goes through it or under it. The only leakage is through the solid rock, and this will take up, as a deposit of silt forms in the reservoir. In fact the whole is as stable as it can be." The strong point with regard to the dam at Tytam was the inner skin. It was not claimed that the whole mass of rubble concrete was water-tight; in fact he knew that it was not water-tight. In order to assist the water which might percolate into the hearting to get out, perforated iron pipes or small perforated bamboos were put in at the various steps. The water-tightness depended upon the skin of the fine concrete behind the ashlar inner face; the rest was mass and weight. He did not know that this principle was novel, but he had never heard of it before in the construction of a dam. With regard to the tunnel, it might be said that the cost was heavy; explanations had been given in the Paper of the cause. Work was carried on day and night, including Sundays, throughout the year for forty-seven months, and he did not know what more could have been done. Very careful experiments were made, and the cost was due principally to the very refractory material which had to be dealt with. Mr. Orange.

General A. De C. Scott wished to make a few remarks with reference to the difficulties mentioned in the Paper on the Shanghai Water-Works, in connection with dealings with the Chinese, as he had had a good deal to do with Orientals in his time. He ventured to suggest that the works described in the Papers possessed special interest, due to the localities in which they were placed, and that there were circumstances connected with them which rendered it desirable to bestow on them a somewhat exhaustive attention. They stood, as it were, on the fringe of countries which had been in the highest degree exclusive, and the inhabitants of which had repelled for hundreds of years, and successfully repelled, the efforts made by European nations to extend their intercourse over the interior. Diplomatists had tried to find the "open sesame" which would unlock the door shut in their faces. They had only succeeded in opening some few ports to trade, and the country to opium. Merchants had tried their hand, but the literati and mandarins despised trade, and progress towards the interior had been arrested. Missionaries had been at work for centuries; but they had not yet induced the Chinese to warm to foreigners, and for political reasons they were disliked by the officials. To his mind it was the engineer who stood the best chance of breaking through the crust of prejudice, distrust, and dislike, which still formed a barrier to intercourse with Europeans, and to the material progress of those countries. He stood before those people as the creator by his skill and knowledge of works which, by the benefits they conferred on communities, were humanitarian in their scope and intention. The very ethics of the people were in his favour. The pious Oriental, who wished to secure his own happy transmigration, commonly planted a grove to shade the wayfarer, or built a road or bridge to aid his progress. He dug a well or a tank for irrigation and the production of food, and not seldom was the Government engineer in India called in to give shape to those good works. In the cases under consideration, 459,000 Orientals at Hong-Kong, Shanghai, and Yokohama were enjoying the benefits of the Euro- General Scott.

General Scott. pean system of water distribution. Each one of them was an agent, more or less active, in disseminating a knowledge of the advantages which he enjoyed. Some stress was laid on the fact of the hostility shown by the officials and others in the native city of Shanghai to the introduction of the water-supply owned by the European Corporation. But it should be recollected that it was not only water which it was proposed to introduce, but a company, and allowances should be made for the Chinese, who very probably might think that there would creep in with the water indefinite claims. He fully believed that before very long there would set in a current of Chinese opinion in favour of the European engineer and his methods, and that members of the engineering profession, and of the Institution, would find in those countries vast opportunities for the exercise of their abilities. Those who were acting there as the pioneers of the profession, and strenuously working against initial difficulties and prejudices would, he was sure, receive the sympathy and support of the members of the Institution, and also the aid which full discussion would give them in the shape of advice and information. He was glad to recognize in Major-General Palmer, mentioned in one of the Papers, an old friend and brother officer in the corps of Royal Engineers, who had, as Chief Engineer, completed the Water-Works of Yokohama, and gained the confidence of the Japanese Government. With reference to the Shanghai works, the system for regulating the filtering seemed to be that of maintaining automatically an adjusted head of water on the filter-beds, such adjustment being made from time to time by a superintendent, and regulating the outflow by a valve. As soon as filtration commenced, the head of water on the filter tended to change, because the filter became foul and a greater head was required. What was really required in filtering was to determine the quantity of water that should be passed through in a given time, in order to give the most efficient filtration; that rate ought to be adhered to, and if that were done it would theoretically involve a continuous alteration in the amount of head placed on the filter. He had seen, in Berlin, a very satisfactory arrangement, in which that principle was carried out by Mr. Gill, who, as the Constructor and Chief Engineer in charge, had made the water-works in that city so admirable an example of what such works should be. Three small chambers had been constructed (*Fig. 4*), which he should call A, B, and C. A abutted against the outside wall of the filter, B abutted on the outside wall of A, and C on that of B, so that the chambers formed a row extending outwards from the filter. A

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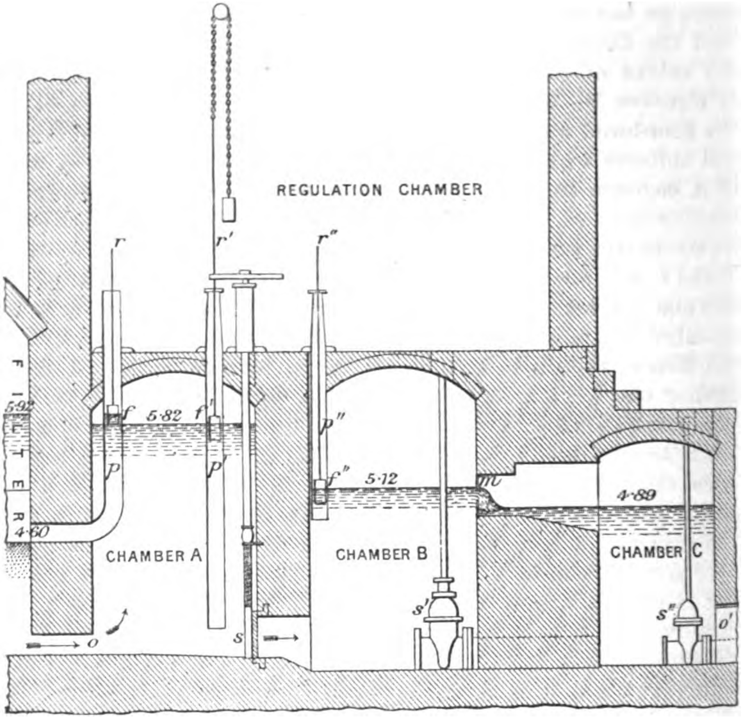
pipe passed through the wall common to A and the filter, the mouth being just above the bed of sand. The pipe, after entering A, was bent upwards and carried through the roof of A into a room built over A and B; floats and rods were fitted to that pipe, to a second pipe in A open to the water, and to a similar pipe in chamber B. Those rods were carried up into the upper room through hollow standards, and graduations and indices were provided in the usual form, so that by means of the first float was read the height of the water on the filter-bed, by the second the height of the water in chamber A, and by the third that in chamber B. In the wall of A, common to the filter, and at the floor-level, was an aperture opening into the latter at its base, and through which filtered water was free to pass. In the wall of A common to B, and also at the floor-level, was an aperture opening into B. That could be closed wholly or partially by a sluice-shutter worked in the upper room. In the wall separating B and C was formed an aperture rectangular in elevation, with its sole about 1 metre 56 centimetres (5·12 feet) above the floor of chamber B, and opening into C. To that aperture, and flush with the face of the wall in B, was fitted a brass or gun-metal plate, having cut in it a rectangular orifice with bevelled edges. A pipe, controlled by a sluice-valve, passed at floor-level from chamber B to chamber C, and gave the means of flushing out A and B when necessary. In C were outlets controlled by valves, and by which water passed to the filtered-water reservoir or to waste, as the case might be. The object of the whole arrangement was to enable a constant head of water to be maintained in chamber B on the thin-lipped rectangular orifice in the metal plate already referred to, and thus to secure a constant discharge from the filter. That constant head on the orifice was secured by the action of the shutter at the bottom of chamber A, regulated by the readings of the gauge-rods and floats in chambers A and B. The flow of water to the filter was also regulated by a sluice-valve, which was automatically controlled so as to maintain a constant depth of water on the filter. As the filter became gradually foul the flow through the material would tend to decrease, but by adjusting the valve in A so as to increase the aperture into B, the charge on the metal plate could be kept up and also the water in A would fall, giving a greater head on the filter required to maintain the normal rate of flow through the sand. At last the water-level in A would fall to the normal level of that in B, when the regulated flow through the orifice could no longer be maintained. The supply was then shut off, and

General Scott. the filter cleaned. The work of regulation was carried out with perfect ease and certainty, and the rate of flow through the orifice was not allowed to exceed 2 gallons per square foot per hour, or 432 gallons per square yard in twenty-four hours. *Fig. 4* had been derived from a plan kindly given him by Mr. Gill. The references at foot would enable the details to be understood. With regard to the water-tower, looking to the great value of the property in the European settlement at Shanghai, and the heavy losses previously incurred by fire, he presumed that the considerable expense of

Fig. 4.



Scale $\frac{1}{50}$.

f f' f'' Floats for indicating level of water surfaces in filter and in chambers A and B respectively.
m Metal plate with rectangular orifice through which water is delivered into chamber C.
o o' Outlets for water from filter into chamber A. and from chamber C to pump well respectively.
p p' p'' Pipes acting as guides to floats *f f' f''* and open at both ends.
r r' r'' Graduated rods attached to floats *f f' f''*.
s Sluice shutter for maintaining level of water-surface in B. Regulates also water-level in A.
s' s'' Sluice valves for emptying chambers and lowering water in filter-bed for cleaning.
The figures at water-surfaces indicate in metres, relative maximum levels in ordinary working, and normal level in B.

General Scott.

£11,849, for constructing a tank containing 150,000 gallons, was unavoidable. Practically, it meant a supply of water for about an hour and a half for a fire. It was evident that without extravagant outlay much could not be done in that way by such constructions. He hoped that some member, conversant with mechanical engineering, would give information with regard to the best adaptation of engines, boilers, and pumps, to meet, in the most economical way, the condition of sudden and considerable variations in the rate at which work had to be done, for this was what scanty storage implied. At Shanghai the winter, he believed, was severe, and there was a considerable degree of frost. He should be glad to know if any difficulty had been experienced in filtration arising from that cause. If frost got into the filtering material, of course filtration ceased. It had been found necessary, in Berlin, to cover in all the filters. There were arches on brick piers covered with concrete and earth. They were, of course, expensive, costing, he believed, £14,500 per acre of filtering surface, as against £7,500 for filters of the open kind. In China, in such a latitude as that of Tientsin, he thought covered filters would have to be used. Some remarks had been made with reference to the subject of waste. It appeared that the rate of consumption was 17 or 18 gallons per head per day. Looking to the habits of the natives, this did no doubt imply waste to some extent, but compared with London, where 30 gallons per head were required, the burden of supply was small. The policy of not stinting the quantity was a wise one. In the Paper on the Tytam Water-Works some account was given of the mortars and cement used; and reference was made to shell lime, and to red earth found on the island. It was curious that a substance which might be considered inert, such as red earth, should produce a good mixture. He had used shell lime in India with burnt brick in powder with good effect as regarded hydraulic properties. That was a different material altogether, having a certain activity and certain powers of combination. He could not understand how the mixture of Portland cement with lime mortar or lime concrete could have any good effect. He thought that home experience had shown that where cement was not very well made, where there was lime in it, which had not been taken up by the alumina, some difficulties resulted; the cement set quickly; the lime mixed with it hardened slowly, being a slower setting material, and in that process of molecular change there was a disturbance, cracks being produced in the quick-setting material by the material which was slow-setting.

Sir Frederick Bramwell.

Sir FREDERICK BRAMWELL wished to ask a question with regard to the Tytam works. He had no doubt, however, that the answer would be so obvious that when it was given he should regret having asked the question. It appeared that the tunnel absolutely passed under the arm of the reservoir where the by-wash was, as shown in Plate 8, Fig. 1; and he wished to know why the entrance to the outlet tunnel could not have been made near this point through the solid rock, thereby saving, say 700 feet of tunnel, and avoiding the outlet in the dam itself.

Mr. Orange.

Mr. J. ORANGE held that it was very desirable to have a clear sight for lining a tunnel nearly 1½ mile long. The point indicated by Sir Frederick Bramwell was simply a creek or arm of the reservoir between two hills; at that point the surface of the ground was about 30 feet below the level of the by-wash, and 70 feet above the level of the lowest outlet of water for the reservoir. A canal 70 feet deep at the tunnel line would have had to be cut leading to the deepest part of the reservoir near the dam, and principally through solid rock, so that the reservoir could be emptied and used. The site was not convenient for the erection of machinery. The question of a well at this point might be suggested from a glance at the plan of the reservoir, but a brief examination of the locality would show the preference for a clear end for the tunnel and well, either in the dam or near it. The tunnel at Tytam could not have been commenced till the 70-foot shaft had been sunk, which would have occupied fifteen months at least. A slight saving of £300 or £400 might have been made, though he was not certain of even that advantage.

Sir Frederick Bramwell.

Sir FREDERICK BRAMWELL said he could understand that there might have been local circumstances justifying what had been done, but it appeared from the statement of Mr. Orange that several hundred pounds might have been saved. For himself he should have preferred to spend a few hundred pounds in doing as he had suggested.

Mr. Burstal.

Mr. E. K. BURSTAL could not perceive the reason why it was impossible to put a valve-shaft in the reservoir. That had been recently done in the Liverpool Water-Works with great success. It appeared to him an objectionable practice to take the pipes through the outside. The use of lime in combination with cement also was a point upon which he should like to have some further information. He could understand the saving of expense, but he thought there were practical objections in the course adopted. He should like to know whether any experiments had been made as to the different rates of expansion, and

Mr. Burstal. whether the different times of setting had any effect. In the Shanghai works, and he believed in the other works, cast-iron pipes had been used. He wished to enquire whether the carriage of the pipes some little distance up the country did not rather point to the use of wrought-iron in preference to cast-iron. He should be also glad to know whether there had been any analysis of the water at Shanghai. In the Paper on the Yokohama Water-Works it was stated that "the service-pipes of the various districts are joined at suitable points, so as to allow of rapid draught in case of fire. The junctions are closed by stop-cocks when the districts are being specially examined for waste." He thought that the system of joining up districts by means of stop-cocks was liable to create confusion. In the first place, in putting on a service every stop-cock in the district must be turned off. Three or four stop-cocks might have to be opened to obtain a full flow. By opening one or two the water was circulated in the district, and the manager naturally thought that he had a full supply. The turncock's business was to open them all, but in nine cases out of ten he did not do so, and thus a false sense of security was created. With reference to the effect of frost on filters, the difficulty generally was to keep up the supply of water to the town; there was no difficulty in getting it to pass through the filters quickly, or it might be obviated by simply laying off one or two of the filter-beds. He was unable to understand the method of regulating the supply for the filters at Berlin. It seemed to be done, not by personal observation of the filter-beds, but by a self-acting apparatus. He thought the regulation could be obtained by simpler means than by that in use in Berlin.

Mr. Hervey. Mr. M. W. HERVEY said it had been stated that the water passing from the Shanghai water-tower was measured by a meter, and that the discrepancy indicated the loss between the pumping-station and the tower. He should be glad to know whether the meter showed that the pumps were delivering as much water as they were supposed to deliver, and whether any allowance was made for slip in the pump-valves. With reference to the filter-beds, it was stated that the average rate of percolation had been 540 gallons of water per square yard per twenty-four hours. Mr. Hervey imagined that during a great portion of the day the rate of filtration would far exceed that amount. The average rate of filtration with the London water companies was between 300 and 400 gallons per square yard in twenty-four hours. The Author had further stated that the filter-beds required cleansing when about 9,000,000 gallons had passed through them, which would be

Mr. Hervey. in about sixteen days. Nothing was said about the condition of the river during various times of the year; no doubt matter in suspension was much more abundant at some seasons of the year than at others, and this would affect the endurance of the filter-beds. With regard to the reservoir, the Author had stated that flushing took place three or four times in the year; it would be interesting to know what amount of sediment was obtained during that time. The settling-reservoirs of the London water-works did not need flushing in many years. Three or four times a year seemed very frequent for cleansing purposes.

Mr. Taunton. Mr. J. H. TAUNTON remarked that no reference had been made to the great expense of the foundations of the water-tower. It was a very well designed construction; but, the base of the tower being 1 chain square approximately, it appeared to him that £4,371, about £1 per square foot, was a large sum of money to pay for it. He had carefully followed the remarks of Mr. Hart with reference to the desirability of substituting a monolith of concrete for the usual preparation of the foundation by piling. But he was disposed to think that if cylinders either of brick or of iron had been used, and the columns had been carried down, especially taking into consideration that important member in the construction, the central shaft, 6 feet in diameter, that would have proved a much cheaper mode of construction. He thought the water was taken from a very bad source; he supposed because a better was not available. There was the refuse of the shipping, of the municipalities and of the native city draining into the river. He would ask if any borings had been taken to ascertain if a subterranean supply was obtainable. The water was described as being full of sediment and creating great difficulties in the filters. Would it not have been worth while to have tried, by a deep boring, whether subterranean water could have been procured and to what extent? And if that was not possible, could not a tunnel have been driven in the gravel, if gravel existed, so as to obviate the taking of the water from so contaminated a source? With regard to the Tytam Water-Works, the conduit, only 3 miles long, and costing £34,700, appeared to be a very expensive work as compared with the cost of similar works in England. He should be glad to know why it was constructed in the way described, and why pipes were not used. There were 18-inch pipes to the town of Victoria beyond the service-reservoir and filters, and he would ask why cast-iron or wrought-iron pipes were not put down, which, he supposed, would have cost only one-third or less than one-half of the amount expended?

Mr. Vernon-Harcourt.

Mr. L. F. VERNON-HARCOURT said that the Tytam dam, as compared with other dams, considering the height to which it might be raised, appeared to be rather narrower at the base than was usual. Also, taking the lines of resultant pressures, with the reservoir full, the line extended beyond two-thirds of the width from the inner face at the top of the foundation block; that was, there was less than a third of the whole width of the dam between the resultant line and the outer face. Now, comparing it with other dams, if the Tytam dam was made the full height contemplated, about 103 feet from the top water-level to the base, it would have a width at the base of 62½ feet as at present. At the Vyrnwy dam, at 103 feet from the water-level, there was a width of about 108 feet. At the Furens dam, one of the highest dams erected, at the same depth there was a width of 87 feet; and at the Gileppe dam there was the large width of 155 feet at the same depth; but, as he had pointed out in a Paper read before the Institution a year ago,[1] that dam was much wider than was necessary, and it was considered that it might possibly be raised 33 feet more to retain a larger quantity of water, and supposing that was done, the width at the same depth would be 117 feet. The width, therefore, of the Tytam dam at the base, taking the additional height into consideration, was smaller than that of any of the principal masonry dams that had been constructed; and remembering that it was a concrete dam, he thought it was undesirable to give it so comparatively small a width at the base. It was a wise plan to have a thoroughly water-tight layer at the inner face of the dam, because there was no doubt that if the water could get into the mass of the dam it would be very difficult to keep it water-tight. At the Gileppe dam, a good deal of water oozed through, in spite of its great thickness; and the same occurred at the higher and slighter Furens dam. As to the making of the concrete, it was always supposed that the concrete was better if it could be kept clean, and, like a previous speaker, he was surprised that some of the earthen materials were added to the concrete, and were found to improve it—a result which he should have thought was almost impossible, unless the material used possessed some peculiar composition not mentioned in the Paper. With very sharp sand, he could understand that it might be impossible to get the concrete thoroughly solid, and that it might be advisable to add some finer sand to ensure compactness; but the addition of material of an

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[1] Minutes of Proceedings Inst. C.E., vol. xcvi. p. 188.

Mr. Vernon-Harcourt. ordinary earthen character could not, he thought, be advisable for such a purpose. He should be glad to know if Mr. Orange considered it advisable, with the line of resultant pressure with the reservoir full coming so far over towards the outer face, to add 10 feet more in height to the dam. At present, this resultant pressure extended beyond the middle third; and with 10 feet additional height, it would be thrown considerably nearer the outer face. It would have been better to reduce the very ample width at the top, and to have widened the base. He thought it was unadvisable, except in cases of paramount necessity, to convey the supply of water through the dam; and in the present instance, this arrangement involved a considerable additional length of tunnel, without apparently any special compensating advantages.

Mr. C. Hawksley. Mr. Charles Hawksley said it would be interesting if the Authors of the Papers would add a little more information as to the prices paid for labour and carriage in the several countries where the works were erected. Some materials had to be conveyed from very great distances, which in England would appear to be almost prohibitory. With reference to the Shanghai Water-Works, General Scott had referred to the mixture of cement and lime, which was generally in England thought to be prejudicial, although he remembered having heard of one case in which it was said to have been used with success. For his own part he would rather avoid it as being open to the difficulties to which General Scott had referred. The water-tower was a structure of unusual beauty, and in that respect formed an example to engineers at home, who did not always sufficiently study beauty in designing their structures, especially those of iron. Mr. Hart had said that it was at times desirable to work with a varying head of water, in which case the pressure from the water-tower was shut off. In water-works it was usually considered better to work with as steady a head as possible; but probably Mr. Hart had some explanation why at Shanghai it was desirable at times to use a varying head. He observed that there was a reflux valve between the tank and the pumping main, and therefore he concluded that no supplies were afforded from the pumping main on its way to the tower, the object probably being to enable the water to be measured by the meters as it left the tank, but he should be glad to be informed on that point. With reference to the settlement of the tower foundations he did not quite follow the tables given in the Paper. The total settlement appeared to have been 2½ inches, of which 2¼ inches seemed to be due to the weight of the foundation, and ¼ inch to that of the superstructure; no further settlement having taken place when the tank was filled with water. Then again, the test block subsided only 1½ inch when sustaining a somewhat heavier load per square foot than that which caused the main structure to subside 2½ inches, a difference the cause of which he did not understand. Mr. Hart had stated that the reason for placing the pumping works and the intake below the city was that the water was there more free from contamination than it was above the city. That might perhaps be due to the presence of a larger quantity of fresh water than was to be found higher up the river; but it appeared to him that as the sewage had to travel down from the city towards the sea, there must at all states of the tide be sewage at the point of intake, since the sewage, which was carried seawards by the ebb-tide, must necessarily be brought back by the flood-tide to a point somewhat lower down the river than that at which it originally entered it, and thus gradually progress towards the sea. The walls and floors of the settling-reservoirs were stated to have been founded on rubble. Perhaps Mr. Hart would explain whether that meant dry rubble or rubble in mortar. A very careful and effective method appeared to have been adopted in building the concrete walls so as to ensure the overlapping of the vertical joints, which was very desirable in walls where reliance was placed on the concrete for water-tightness, and where they were not puddled at the back. The importance of washing the sand for mortar, and even for concrete, appeared to have been fully recognized not only at Shanghai but also in the case of some of the works described in the other Papers under discussion. He was somewhat surprised to find that in one instance earthy material had been mixed with lime. Usually the adoption of that course would result in failure; but there were certain materials which did not appear to operate in that way. He believed that at the present time Mr. Hill was using at the Thirlmere Works material which was locally known as scammel; it had the appearance of being mixed with clay, yet it made a most excellent concrete, and was used instead of sand. Care, however, had to be exercised in the selection of that material, because if inferior scammel was used, the results, he believed, were not satisfactory. At Shanghai balance-valves were mentioned as having been used as inlets for the filter-beds. Similar valves had been introduced by his father when he first constructed the filter-beds at the Derby Water-Works about forty years ago. They answered their purpose exceedingly well, and he had no doubt that the valves described in the Paper and which were even of a more delicate construction, would be found to operate satisfactorily. It would be interesting to learn from Mr. Hart the

Mr. C. Hawksley.

Mr. C. Hawksley. amount of the settlement in the foundation of the chimney, which was apparently subjected to a heavier pressure per square foot than the foundation of the tank. General Scott had referred to the liability of the filter-beds to be frozen. He believed there was only one instance in which covered filter-beds had been used in England, namely, at the Weardale Water-Works where the filter-beds were situated at an elevation of nearly 1,100 feet above the sea, and where it would have been almost impossible to keep open filter-beds in order during a severe winter. The filter-beds to which he referred had now been in regular use for the past nine years, and were worked without difficulty, never having had more than a very thin skin of ice upon them; they were cleaned regularly during the winter, and no difficulty whatever had been found in working them continuously throughout the severest frosts. The roofs were constructed of timber carried on brick walls and iron columns, and were boarded and slated. In the side walls were openings for light and ventilation, which could be closed at will by shutters and large sliding doors in the end walls afforded access to the filter-beds. With regard to the Paper on the Tytam Water-Works, he had found it somewhat difficult to follow the description of the stratification beneath the dam, and he thought it would conduce to a better understanding of the description if the Author would indicate the stratification on the longitudinal section of the dam. He observed that the supply from the reservoir during "ordinary summers" was referred to in the Paper; but when determining the capability of water-works it was essential to reckon only on the supply that could be derived during the driest summers, or rather during such a dry period as could be tided over by the reservoir. If calculated on any other basis the supply would only be intermittent, and would fail in a dry period just when the water was most wanted. A section was given of the draw-off valves, which were placed at various levels apparently with a view of utilizing the upper stratum of water in the reservoir, the object, he supposed, being to obtain the clearest water; but, having regard to the fact that the valves were placed on the internal diaphragm in the valve shaft, and not on the apertures through the external wall communicating with the reservoir, it appeared to him that the object in view would not be attained, because the water was free to enter at any of the five apertures, between the draw-off well and the reservoir, which happened to be submerged at the time. A considerable quantity of puddle appeared to have been conveyed a distance of no less than 80 miles, and it would be interesting to learn how it was

Mr. C. Hawksley.

conveyed and at what cost. There seemed to be only a height of 2 feet between the sill of the by-wash and the top of the dam. That was a very small margin, and from what the Author had stated it appeared that the water on one occasion flowed over the sill of the by-wash 4 feet in depth, and must, therefore, have risen to a height of 2 feet above the top of the dam, depending in that instance for its retention within the reservoir on the parapet wall built on the top of the dam; had that wall given way the water would have flowed over the top of the dam and fallen with great force down the front. With reference to Mr. Turner's Paper on the Yokohama Water-Works, it did not appear very clear why a pumping-station was needed. Indeed, from the section of the pipe-line which was given (and which, he thought, required, to make it clear, to be continued as far as the intake), it would seem as if the pumping-station could have been dispensed with altogether. It might be, however, that the pipes followed the lowest available line, and that without a pumping-station considerable cuttings and tunnels would have been necessitated. No doubt there was a satisfactory explanation, otherwise a pumping-station would not have been erected, but it would be well if the Author would afford the needful information. An ingenious apparatus, which, so far as he knew, was novel, was described in the Paper, for recording the differential height between the surfaces of the water on the inlet and the outlet sides of a gauge. The Paper referred to the expansion of the pipes, consequent on their exposure to the great heat of the sun whilst being laid and to their subsequent contraction. He thought it was very fortunate, even from that point of view, that lead joints were adopted and not bored and turned joints; otherwise the difficulty experienced would have been increased. It seemed that in the town ball fire-hydrants were used. In England great difficulty had been found with that form of hydrant, inasmuch as dirt got into the hydrant box, and when the pipes were emptied the ball fell and admitted the dirt into the pipe. It was to be feared that a similar difficulty would be experienced at Yokohama. That difficulty had led to the more general adoption of the screw-down hydrant, in which a valve (opening upwards) was held on to its seat by a screwed spindle, and therefore always remained closed except when the spindle was raised and the valve was lifted by the pressure of the water beneath. The puddle used seemed to have withstood with great success the shocks of earthquakes to which it had been subjected. He had known the masonry wall of a reservoir, even in Great Britain, to be so damaged by a shock of

Mr. C. Hawksley. earthquake as to necessitate its being pulled down and rebuilt. He understood, however, that in Japan the earthquakes were of a rather different character from those experienced in many other places. They were described as taking the form of a long undulating motion, and therefore not so liable to do damage to masonry or puddle structures as the earthquakes sometimes experienced in Europe.

Mr. Hart. Mr. J. W. Hart, in reply, said that General Scott had referred to the feeling against companies in Shanghai, as a reason for the disinclination of the Chinese to encourage water-works so introduced. He was entirely in error in that respect. Shanghai possessed a great many companies, and many subscribers were the Chinese themselves. In the water-works they owned a large proportion of the capital. They had no aversion whatever to companies.

General Scott. General Scott said he referred to associations in general of English people called companies, and to the feeling of the Chinese as to the introduction of foreigners giving rise to indefinite claims.

Mr. Hart. Mr. J. W. Hart observed that the works were entirely within the scope of the foreign settlement, and the supposition of General Scott could not possibly apply. Foreigners had a perfect right to form companies there, and the chief contributors were Chinese shareholders. Those who mainly objected to the water-works were dealers in water, water guilds who retailed buckets of nauseous water at high prices. General Scott had also referred to the water-tower as being a convenience in the case of fires only. That, however, was only one of its conveniences. It was important, if there was occasion to stop the engine, that the town should not be left without water. It was also important to have a reserve for night service, enabling the engine to be at rest. No inconvenience, such as had been suggested, had arisen from frost in connection with the working of the filters. The question of the varying rate of filtration, and the balance-valves for supplying the filters, appeared to have raised an issue far more important than was ever intended. The chief reason for introducing the valves was to prevent the Chinese from running the water to waste. The valve at the outlet-well was only regulated to accommodate the rate of percolation intended, but if the water had not been carried away it would have run to waste; the inlet-valve would have been opened wide by the Chinese, and a result would have been brought about such as he had described. The balance-valve was controllable when the filters were in operation, and the head of water could be increased as was thought proper. Reference had been made to the cost of the foundation of the water-tower, and the suggestion put forward that it would be more desirable to have built the foundation of cylinders. That, however, was an erroneous idea. There was a firm stratum of about 20 feet below the surface, and below that, liquid mud. In the case of a bridge built about fifteen years ago, screw-piles were driven through the firm stratum, and the bridge tumbled down by its own weight before a single passenger had passed over it. The suggestion as to boring for water was not a new one. Twenty-five years ago there was a boring of nearly 200 yards for that purpose; but from the mere fact of its being an alluvial deposit, it was almost certain that a boring might be pierced to an indefinite depth, without striking a water-bearing stratum. Any attempt, therefore, to bore for water was out of the question. It had been stated that settling-tanks in England were not cleansed for years. He was glad to hear it. He could only say that if such a practice was followed in Shanghai it would only take two or three years to fill them with deposit. It was impossible to arrive at any direct or absolute statement as to the amount of sediment because it varied so much with the state of the river. Sometimes large volumes of water came down bringing an extraordinary amount of deposit, while on other occasions, when the weather was fine, the water was comparatively clear. Such variations might take place five or six times in a month. It was, therefore, a most difficult matter to form any direct conclusion as to the amount of deposit taking place, because no two periods of the year were exactly alike. The tanks were cleaned out three or four times a year, and about 18 inches to 2 feet of mud were always removed. He thought the Author of the Paper on the Yokohama Water-Works was in error in stating that there was no drainage system in Yokohama. There was a perfect system of drainage by Mr. R. H. Brunton, M. Inst. C.E., as early as the year 1870. Mr. Hart had reported on a water-supply for Yokohama in that year, and he felt sure that Mr. Brunton and other engineers had done the same. Mr. Hart.

Mr. ORANGE, in reply, said that the red earth used in Hong-Kong was of a very greasy nature, and it was the common material for mortar of the country; it was a first-class hard mortar, was extremely suitable for brickwork, and would set very well even under a slight head of water. He had never compared the constitution of the red earth with puzzolana; but Mr. Price used to call it a sort of puzzolana. He had not used any of the shell-lime with the red earth in the Tytam dam. In the case of other dams from 30 to 40 feet high, he had used the red earth and shell- Mr. Orange.

Mr. Orange. lime with a small amount of cement, which he found on experiment considerably quickened the hardening and increased the strength, and he thought it was worth while to spend a little money in order to get on with the work more quickly. He had also experimented with the red earth and cement with no lime at all, when the ordinary English Portland cement, mixed with red earth, set very well indeed. He had given some examples of rough tests with briquettes of cement and red earth. If iron pipes had been used for the conduit instead of masonry, the cost of the conduit would have been doubled. The carriage of the iron pipes would have greatly increased the cost. Mr. Taunton should remember that the cost given in the Paper was for a road besides the conduit. As to the question of the section of the dam, it was impossible for him to enter into it off-hand. He could only say that the dam was built and was still standing, and there had been a depth of 2 feet of water above the top of it; he thought, too, that it was one of the driest dams in existence. The Furens dam, mentioned by Mr. Vernon-Harcourt as a good dam, leaked like a sieve; the Tytam dam did not. With reference to the sand, what he meant to say was, that if the sand was very sharp, when cement was put with it the water ran through and carried it away. It was impossible to make a close concrete with very sharp sand; it had to be a little thick, loamy and close, in order to make a close concrete. That was why, when the sand was sharp, he always used a certain portion of the siftings of the stone from the stone-breakers, which was almost dust, in order to make the mixture close. It was a rule in the profession that for strength sand should be clean and sharp, but for closeness he did not want it too sharp. It would be very difficult to show the stratification by a diagram, because it was so irregular, and he thought it had been sufficiently described in the Paper. A question had been asked with regard to the level of drawing off the water in the valve-well. Opposite each valve in the mid-feather, which divided the wet from the dry well, was an opening into the reservoir through the dam; so that it was equivalent practically to the valve being on the outside of the dam. There was a head of 4 feet over the by-wash; in other words, 2 feet above that of the dam. The fence-wall was a continuation of the ashlar inner face and the concrete inner face. It was a strong structure, made to withstand any possible head of water.

Mr. Turner. Mr. J. H. T. TURNER, in reply to Mr. Charles Hawksley, stated that the pipe-line followed the lowest available line of country. The fall of the River Sagami was such that it would have been possible, Mr. Turner.

by extending the aqueduct for several miles, to dispense with pumping. But, taking into consideration the cost of carrying the main-pipe higher up the river, the severe character of the floods, the large variation of water-level in the narrowing cañon, and the increased difficulties of access to works situated at any point higher up than Mii Mura, it was found to be desirable and economical to establish small pumping-works at the intake, to raise the water at all times into the conduit, whence it flowed 27 miles by gravitation to the Nogeyama reservoir. It might be correct to characterize Japanese earthquakes generally as large waves of earth. But of course the period and rate of propagation of the waves depended upon the proximity of the point of observation to the seat of disturbance. At Yokohama, he had seen walls split, and solidly built brick chimney-stacks projected through the roofs of the houses by the violence of the earth-waves. From his own observation of such effects, and from personal sensations during one particularly destructive earthquake, he considered that it would be imprudent to rely upon obtaining water-tight structures of brick, masonry or concrete, without puddle, at least in that immediate locality. As to the drainage of Yokohama, Mr. Hart must surely be misinformed. During the progress of the laying of some 50 miles of pipes in the streets, he became well acquainted with the drainage system as it existed in 1885. Excreta and urine were removed in pails from the houses and were carted away for manure. But the ordinary street drains, in five-sixths of the town, consisted of wooden shoots about 6 inches square in cross section. The main drains had flat wooden floors and covers and stone sides, with open joints. Many of the drains were choked with slime, and all that were opened were surrounded by earth saturated with sewage. In the remaining sixth of the town there were brick drains, which lacked adequate ventilation and flushing arrangements. He therefore considered himself justified in alluding to the absence of a good drainage system at Yokohama.

Correspondence.

Major-General Palmer.

Major-General H. S. Palmer, as the Engineer of the Yokohama Water-Works, wished to say a few words by way of supplement to Mr. Turner's Paper. First, as to the works at the intake. To any one unacquainted with the local features and conditions, the questions might very well occur:—Why was pumping resorted to at all at the head of a gravitation supply; and why, in the second

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place, was it found necessary to pump into a settling-tank placed as high as 34 feet above flood-level? The answer to the first of those questions would be, that, owing to the great fluctuations of the level of the stream, ranging over fully 20 feet, and to the rocky and precipitous nature of the river margin, the construction of a pipe-aqueduct that would be effective at all times without the introduction of pumping was practically prohibited, on the grounds of difficulty and expense. It had to be borne in mind that the intake was in the heart of a formidable river cañon, walled in by rugged cliffs and slopes. Assuming a gradient of 6 feet per mile for the pipe, and (which was about correct), a fall of 22 feet per mile for the stream, and that the first pipe was placed 3 feet below low-water level, it would have been necessary to lay the first 1½ mile of the aqueduct in the zone between high-water and low-water, in bare rock, or rock with a shallow, loose covering of shingle; and the work would have been liable to all the inroads and interruptions of a river subject to freshets of sudden and dangerous violence. It was unquestionable that this consideration alone, not to speak of others less obvious, left him practically no alternative but to introduce pumping, that should, at least, lift the water clear of flood-level. As to the second question, namely, the raising of the water some 34 feet higher, he had been guided to this also by a careful study of the best and cheapest way of dealing with the problem. Those 34 feet, he had found, gave, in addition to the extra head affecting the first 18 miles of aqueduct, a much better and easier pipe-line out of the river gorge, and much advantage in surmounting the elevations on the hither side of Kami-Kawai, which was the lowest point of escape from the basin of the Sagami River. Further, the main part of the cost of the pumping-station lay in the preparation of the site itself, and in the buildings, foundations, suction-well, quarters, and other accessory works. The additional prime outlay involved in machinery adapted for the 34-foot lift, coupled with the sum representing the extra annual cost of pumping, had been carefully compared with the probable extra expenditure if no such lift were resorted to, and had been found largely in favour of the higher level. It might be asked, however, even after this explanation—Could not the same result have been got by continuing the higher pipe-line up stream, at its grade of 6 feet per mile, until the high-water level was struck? Of course, this could have been done, if the cost had not forbidden it. But, as a matter of fact, the natural difficulties increased so greatly above the point of intake, that a continuation of the pipe-line for some

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2 miles upwards would have been ruinously expensive, not to speak of the highly unfavourable nature of the river-margin thereabouts for forming an intake station. For all these reasons, he had come to the conclusion that the problem was to be best solved by placing the intake at Mii-Mura, and introducing a total lift of 54 feet from low-water level. And he might add that he had extended his investigation to points below as well as above Mii-Mura, with the result above stated. There was one more point, referred to by Mr. Turner, on which he wished to dwell with some emphasis. That was, the precautions taken against earthquakes, as in the adoption of lead joints for the pipes, and the encasing of the service-reservoir, filter-beds, and other water receptacles in puddle, freely used and prepared, and laid with the greatest care. If any critics should be disposed to think such precautions needless, or overdone, he would urge them to bear in mind that the personal experiences of earthquakes in the Yokohama district, which had been gained by foreigners during their thirty years of intercourse with Japan, were not necessarily any real measure of the risks or even the probabilities of the case. No engineer would dare to argue solely from the records of such an insignificant period. Rather, he would take a wider survey, looking back to the stories which the remoter past had to tell, considering the seismic conditions of the region in which he had to construct his works—and in Yokohama those conditions were distinctly precarious; and would remember that, while no human foresight could fend off the havoc which attended the graver class of convulsions, it was at least his duty to exercise all possible care as against preventable injury from the shocks, not uncommon in Japan, which, while far short of being cataclysmal, were yet severe enough to work very serious injury upon solid structures built in Western style. As regarded Yokohama especially, its situation was on one of the chief lines of volcanic weakness in Japan. It so happened, moreover, that even the last half-century had afforded ample warnings. In proof of this, he might mention the great earthquake at Tôkiô (only 18 miles from Yokohama), in 1855, which destroyed some sixteen thousand houses, and brought death to tens of thousands of the people. Or, again, the latest serious warning, namely, the earthquake of no longer ago than the 15th of January, 1887, which, originating some 30 miles south-west of Yokohama, spread its effects over 27,000 square miles of country, and wrought very considerable damage in the town itself, as well as in the capital. In the full account of this earthquake, which appeared in *The Times* some three months later,

Major-General Palmer. it was shown that in the region of chief activity, namely, at a distance of only between 20 and 30 miles from Yokohama, "Professor Sekiya counted no fewer than seventy-two cracks in the ground, in a distance of 7 miles, one of them being a foot wide and 500 feet long;" that people walking abroad were thrown to the ground; that a large river became "so strongly agitated that the ferry-boat could not be taken across it for some time after the shock," and so on; and, further, that, "had the maximum intensity reached Yokohama, it is more than likely that not a chimney would have been left standing; and that, in the foreign quarter, at least, there would have been heavy ruin and loss of life." Plainly, then, it was not necessary to go far for evidence amply sufficient to refute any attempt to belittle earthquake risks in Japan. To ignore such practical admonitions as the foregoing would be to live in a fool's paradise. And, in his opinion, the engineer would be culpably negligent who failed to take past evidence and future risks into account in his designs, and to carry his anti-seismic precautions as far as was reasonably practicable.

Mr. Perrett. Mr. E. Perrett observed that water-works, of the kind described, were generally provided to give the inhabitants of a district an abundant supply of fairly pure water; but neither of the Papers contained an analysis of the water as it entered the works, and as it was supplied to the consumer, and there was a question as to its condition. But there seemed to be no doubt that the water in all three cases was liable to be heavily charged with matters in suspension. The method adopted for cleaning the water was filtration, such as had been used for several years with fairly good results. In this arrangement, when dirty, the surface of the sand was scraped off, washed, and put back; but nothing was known of the cost of this process. The ordinary rate of filtration through sand was 2 to 3 gallons per square foot of surface per hour, the upper surface of the filter only being in action, the lower and large bodies supporting the fine sand. The cost of the filtering material was small; the chief expense (omitting land) was the construction of the filters and the cost of cleansing them. In an arrangement with which he was connected, a more expensive, but a more efficient filtering material had been adopted, namely, a mineral carbonaceous matter, by which the rate of filtration was increased at least twenty times, owing to the porous nature of the material, which was unlike sand in that respect. To effect the cleansing of such material, perforated pipes were placed under the media, and slightly compressed air was supplied, which, violently agitated, cleansed, and aerated the filtering material; a small reverse current

Mr. Perrett.

of water carried the dirt away, and in a few minutes the cleansing was effected. A great advantage of effecting the cleansing by mechanical means was that it could be done every day, and the passage of the water through the accumulated dirt, which in the case of an infrequently cleansed filter was very objectionable, was avoided. The size of the filters was reduced by this plan to at least one-twentieth, the cost of cleansing was practically nothing, and the cost of the filtering arrangement itself was very small.

Mr. Symons.

Mr. G. J. Symons remarked that there were two points in the Papers upon which some further meteorological details would perhaps be acceptable. In the Paper on the Hong-Kong Water-Works reference was made to a slip of 25,000 cubic yards of earth, and to other damages, as resulting from "a deluge of rain in May 1889." But no details were given as to the amount of rain. The fall, however, was so great as to be worthy of setting out *in extenso*. There were two rain-gauges in operation; in so enormous a rain precise agreement was not to be expected, but they agreed very fairly. One gauge was measured four times, and opposite its record was entered the total by the Observatory gauge.

1889.		Interval.	Gauge measured four times.	Observatory Record.
		Hours.	Inches.	Inches.
May 29th.	3 a.m. to 7 a.m. .	4	0·90	0·90
"	7 a.m. to 0.30 p.m.	5½	11·56	10·13
"	0.30 p.m. to 7 a.m. 30th	18½	11·54	17·95
May 30th.	7 a.m. to 10.15 a.m.	3¼	1·66	0·62
	Total . .	31¼	25·66	29·60

The Table in the following page gave the fall at the Observatory in each hour.

From this it would be seen that in the twenty-four hours, ending 6 A.M. on the 30th of May, the fall reached the enormous total of 28·44 inches, being considerably more in that one day than fell in London in an average year. It might, however, be noticed that there was no hour in which the fall exceeded 3·40 inches; therefore the rate of fall was not greater than had been recorded in England, and the special characteristic was the long duration of an intense fall. The general feature of the fall had been already illustrated.[1] In the Paper on the Yokohama Water-

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[1] Symons's Monthly Meteorological Magazine, vol. xxiv. p. 104.

Mr. Symons.

HOURLY RAINFALL AT HONG-KONG OBSERVATORY.

—	May 29th.		May 30th.	
	In Hour.	Total.	In Hour.	Total.
	Inches.	Inches.	Inches.	Inches.
1 a.m.	..	..	1·80	15·41
2 "	..	..	2·30	17·71
3 "	0·08	0·08	3·20	20·91
4 "	0·20	0·28	3·40	24·31
5 "	0·08	0·36	3·00	27·31
6 "	0·14	0·50	1·63	28·94
7 "	0·40	0·90	0·04	28·98
8 "	1·44	2·34	0·58	29·56
9 "	0·46	2·80	0·02	29·58
10 "	3·07	5·87	0·07	29·65
11 "	3·35	9·22	1·03	30·68
Noon	1·27	10·49	0·55	31·23
1 p.m.	1·08[1]	11·57	0·55	31·78
2 "	..	11·57	1·20	32·98
3 "	..	11·57	1·12	34·10
4 "	0·37	11·94	0·01	34·11
5 "	0·40	12·34	..	34·11
6 "	0·03	12·37	..	34·11
7 "	0·02	12·39	..	34·11
8 "	0·07	12·46	..	34·11
9 "	0·20	12·66	..	34·11
10 "	..	12·66	..	34·11
11 "	0·11	12·77	..	34·11
Midnight	0·84	13·61	..	34·11
Total	13·61	13·61	20·50	34·11

Works, it was stated that "It was difficult, and often impossible, to obtain information about such matters as rainfall, evaporation, etc." It would hardly be gathered from that statement that there was, and had been for several years, a well-worked Meteorological Office in Japan, and that observations at Yokohama dated back to 1863. Ample materials for a very creditable monograph on the rainfall of Japan existed in 1885, when these works were commenced; for not only were there eighteen stations, scattered over the country, at which regular observations were made; but, for the Imperial Observatory at Tôkiô, both for rainfall and for evaporation, the observations had been made with a completeness rare in this country, and the values had been published.

Mr. Walker.

Mr. THOMAS WALKER stated that, in 1887–88, he constructed a covered service-reservoir to hold 5,000,000 gallons of water on

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[1] In another report this value is given as 0·08; if that is true, the totals in the Table for each subsequent hour should be 1 inch less, and the gross total 33·11 instead of 34·11.—G. J. S.

Addington Hills, near Croydon. It was made entirely of concrete, no puddle having been used; and, as the reservoir was perfectly water-tight, a few particulars might be of interest to the Institution. The hills were composed of the water-worn pebbles and fine sands of the Oldhaven beds, and these materials were chosen for the concrete, a portion of the sand being removed by screening. The contour of the ground necessitated the reservoir being oblong; the inside dimensions were 420 feet by 124 feet by 16¾ feet deep. The floor, outer walls, and roof were of Portland cement concrete, 6 to 1 by measure; and for the piers and arches of the longitudinal and cross walls, up to the springing level of the covering arches, the proportions were 5 to 1, a little Thames sand being used. The concrete was hand-made, turned over twice dry, wetted from a rose on india-rubber tubing, and thoroughly mixed on wooden platforms. It was not dropped from a height into its final position, but placed there with a shovel in layers, not too thick, so that the coarse and fine parts of the concrete were laid or mixed together equally and well worked, ensuring solidity throughout. Water was rather freely employed, but not so as to stand on the surface of the concrete when in position. For joining up all old work when it was set, grout made of 1 part of cement to 2 parts of Oxted sand was used, and, when necessary, the old work was cleansed, roughed over with a pick, and brushed before the grout was applied. The floor was 18 inches thick, put down in two layers with overlapping joints. The inside of the outer walls (which required to be roughed) and the floor were carefully rendered, the first coat ½ inch thick with cement and washed Thames sand in the proportion of 1 to 1 of each, and the finishing coat ¼ inch thick was of neat cement put on before the first coat was quite set, and thoroughly well trowelled to a smooth hard face. A double thickness of rendering was laid under the piers and on the springing of the arches against the outer walls. The rendering might be said to line the floor and sides of the reservoir in every part up to 6 inches above overflow level. Fifteen slight vertical cracks, that appeared in the outer walls before they were rendered, were cut out in a V shape, with a cross-sectional area of about 1 square foot, and filled in with good concrete. Careful examination after the reservoir had been in use failed to detect the slightest fracture in the rendering in any part of the work. The outside of the concrete arches forming the roof was covered with asphalt ¾ inch thick, in two coats, and was found to be water-tight. The spandrels of the arches were inclined from the centre to the ends of the reservoir, and had 3-inch land drains laid along them to carry off Mr. Walker.

Mr. Walker. surface water. A party-wall, 12 feet high across the reservoir, allowed the water on either side of it to be run off independently of the other. The main from the pumping-station entered each division at the springing level of the roof arches, which was also the overflow level, and a water-cushion was formed on the floor under each inlet by walls 2 feet high enclosing a space 10 feet by 6 feet. The surface of the hills over the reservoir had been restored and planted with heather as before.

Mr. Turner. Mr. J. H. T. Turner, in reply to Mr. Symons, pointed out that the very complete meteorological establishments at Tôkiô, Yokohama, and the sixteen other stations in Japan, though doubtless most serviceable in their respective localities, could afford but little aid in ascertaining the meteorological conditions which prevailed in the water-shed of the Sagami. Meteorological stations at important places were of great use in a country, such as Japan, subject to violent atmospheric phenomena, as a means of recording and predicting the same. But, for the purposes of an inquiry into a supply of water to be derived from the distant water-shed of the Sagami, it would not be advisable to apply statistics gathered at Yokohama or Tôkiô, as these places were subject to their own special meteorological influences. Meteorology had not yet become so wide-spread in Japan as to afford engineers information with respect to the less thickly populated, and therefore for water-works purposes, more important districts, as was the case in Great Britain.

25 February, 1890.

Sir JOHN COODE, K.C.M.G., President,
in the Chair.

The discussion upon the Papers by Mr. J. W. Hart, Mr. J. Orange, and Mr. J. H. T. Turner, on Water-Works in China and Japan, occupied the whole evening.

SECT. II.—OTHER SELECTED PAPERS.

(*Paper No. 2384.*)

"The Deep-Water Quays in the Port of Cork."

By PHILIP BARRY, M. Inst. C.E.

THE "Port of Cork" includes Cork and Queenstown (formerly called Cove), the river, and all tidal inlets within the harbour entrance. The port is under the control of one body, the Cork Harbour Commissioners, thirty-five in number.

The following extract from the second report of the Tidal Harbours Commission, dated 20th March, 1846, is of interest as representing the state of the harbour forty-three years ago:—

> "The celebrated harbour of Cork stands pre-eminent for capacity and safety, even in that country of fine natural harbours. The upper portion of it, which falls more immediately within the limits of this Commission, extends for 5 miles below the city to Passage. This part, since the year 1820, has been considerably deepened; vessels of 500 tons now come up to the city, and the traffic and income of the port have proportionably increased; yet the harbour is far from being in that state which a revenue of £8,000 a year for the last twenty-five years would warrant. Complaints are made that banks at the foot of the quays cause great risk to the fine steamers which ply between the city and Cove; that seven weirs cross the river Lee within 1½ mile of Cork, and impede the upward flow of the tide; that a wall has been built for 1,500 yards in a doubtful direction to guide the set of the current, and is now left in an unfinished state; that the silt dredged up from the channel is laid at the back of this wall, and washed down again into the river by every high tide; and that an area of 150 acres, over which the tides used to flow, has been partly enclosed, whereby a large portion of tidal water is excluded. Yet this large space, if enclosed by a wall properly directed, and the loss of the excluded water compensated by dredging the upper part of the bed of the river, might be a benefit to navigation, and form a park for air and exercise for the citizens, instead of being left as a nuisance; in short, to quote the words of a highly respectable witness, 'the harbour of Cork has throughout been the victim of half measures.'"

The 150 acres above referred to have been enclosed and are now called "The Park." The old quays at Cork have been protected by sheet-piling, and the water has been deepened alongside by dredging to 5 and 7 feet below low-water. Great improvement has also been effected in the river. There is now a channel from 250 to 300 feet in width, 5¼ miles in length from the city to deep water near Passage, with a depth of 14 feet at low-water spring-tides.

When the Author became Engineer to the Harbour Commissioners, in May 1873, there were no deeper berths for vessels than at the old quays above-mentioned, with 7 feet at low-water, and there was urgent necessity for better accommodation. To provide this, with the least possible delay, a timber wharf was constructed at Cork in front of Victoria Quay, 1,024 feet in length, projecting 20 feet outside the quay wall. This projection enabled the river to be dredged without endangering the quay, so as to afford a depth of 19 feet at low-water for vessels lying at the wharf. The timber wharf cost £11,544, and was immediately used to its fullest capacity by grain vessels, which had previously discharged their cargoes at Passage into lighters, by which the corn was brought to the city.

It was then debated whether further extensions should be provided by tidal-basins, wet-docks, or deep-water quays on the river frontage. Deep-water quays were, on the advice of the Author, finally adopted. They afford the necessary accommodation in the most economical manner, and admit of being built, from time to time, of such extent only as the trade of the port requires. The river was of sufficient width to admit of such quays, and the range of tide was not too great, being 13 feet at springs and 10 feet at neaps. These quays were constructed under three separate Acts of Parliament, and as the works were, to a certain extent, distinct, they will be described separately.

DEEP-WATER QUAY, SOUTH.

As authorized by the Cork Harbour Act of 1875, this quay was 3,900 feet in length, but only 650 feet were constructed. The line of quay was within the existing river-wall from 50 to 100 feet, and the river was to have been widened to that extent by the construction of the quay.

The Author decided to construct this quay on the cylinder system (Plate 11, Figs. 1 and 2), having calculated, as against the heavy block-system, that the expense of sinking cylinders would be counterbalanced by the amount of excavation and consequent filling saved, the extra excavation for blocks, including work of divers, having been estimated at £10 10*s*. per lineal foot of quay.

The site having been first excavated to the level of the new quay surface, a trench was cut 20 feet in depth, and 20 feet wide at the bottom. At this depth (3 feet under low-water level) gravel was reached, the ground above being compact mud and clay, unsuitable for cylinder sinking.

In the trench so formed timber casings were laid, and the cylinders were built on the spot, of concrete in the proportion of 5 to 1, in rings 10 feet high at each operation. The process of sinking was carried on by two 4-foot 6-inch Bruce's diggers, worked by steam-cranes travelling on the bank above. The so-called cylinders were oval, with semicircular ends, one oval forming the full depth (18 feet) of foundation from face to back. These columnar foundations were designated "cylinders," and the term is retained for convenience.

To afford time for each length of cylinder to consolidate, and to obviate the delay consequent on the construction in position, the cylinders were laid in two isolated sections, separated from each other by the breadth of several cylinders. Each section was worked from both ends, thus enabling the construction and sinking of the cylinders to be carried on at four points. When the sections approached nearer to each other than the breadth of an ordinary cylinder, they were connected by an iron closing cylinder, which was sunk to the full depth with the greatest facility.

Two 8-inch centrifugal pumps were employed to keep the trench dry. The water-level in the interior of a cylinder was usually from 12 to 18 inches above the level of the water outside.

The cylinders were at first sunk without shoes, the concrete at the base being moulded into a cutting edge. They were subsequently shod with metal shoes, weighing 2 tons 6 cwt., which cost £26 12*s.* each. These shoes did not facilitate the sinking of the cylinders to the extent anticipated, and, in the opinion of the Author, might have been dispensed with. The cylinders were sunk 6 to 7 feet under the intended bed of the river, and were then filled for their entire height with concrete. The recesses for dowelling were closed by American elm piles, with concrete in small bags packed between the piles.

The cylinders were capped with a continuous block of concrete, 15 feet by 3 feet in height, upon which the superstructure was built in the usual way. In front, where this concrete block bridges the recesses or bays between the cylinders, three ordinary railway rails were built into it.

The average rate of sinking the cylinders, for the full depth of 26 feet, was 1 foot in two and a half hours when weighted with 70 tons of metal, and the average cost (including removal of gravel and sand) was 10*s.* per foot.

Great difficulty was experienced in supporting the cranes travelling on the top of the trench, owing to the gravel underlying the slopes being drawn into the cylinders by the action of the digger. It was found necessary, after a short time, to sheet-pile the bottom of the trench. The expense of this piling, and of pumping, finally led to the abandonment of the cylinder mode of construction, and only 241 feet in length of quay were built on that design.

The Author believes the difficulties encountered in sinking these columnar foundations would have been in a great measure overcome if they had been more heavily weighted, but circumstances would not admit of the outlay on special weights necessary for that purpose.

In filling the cylinders with concrete deposited through water, it was invariably found, after several feet had been deposited and allowed to rest, that the upper layer of about 18 inches of concrete had taken no set, but was composed of a soft milky substance, hot, like freshly-slaked lime, and which, when exposed to the air, dried very slowly, and consolidated into a very light and rather friable mass. Analysis showed this substance to consist of the same ingredients as the cement, and in nearly the same proportions, except that the former ("laitance") contained only half the quantity of lime, more carbonic acid, and a large quantity of moisture.

The following is the result of the chemical analysis, No. 1 being the cement used, and No. 2 the "laitance":—

	No. 1.	No. 2.
	Per cent.	Per cent.
Soluble silica	23·70	21·02
Insoluble silica	trace	trace
Alumina	8·57	11·12
Peroxide of iron	3·65	
Lime[1]	57·33	28·84
Magnesia	3·50	3·75
Carbonic acid (CO_2)	1·57	6·70
Sulphuric acid anhydride (SO_3)	1·68	1·82
Moisture	trace	26·75
	100·00	100·00

In consequence of the unexpected acquisition of a new frontage on the north side of the river, subsequent to the Act of 1875, it was determined to abandon the construction of this quay on the south side, except so much as was in progress, namely 650 feet in

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[1] A proportion as hydrate of lime; hydrate did not come out in No. 2.

length. The cylinders having been sunk to the full depth for 241 feet of quay, the remaining portion, 409 feet in length, was built with concrete blocks three in height (Fig. 3).

On the completion of the quay, the ground in front of the cylinders was dredged to 23 feet below low-water, as had been done on the block-section. No settlement took place in this quay, and the alignment of the coping for the full length of 650 feet is unusually true.

The cost of the entire quay, including one-half of the total cost of the plant used in its construction, was £37,546, or £57 15*s.* per lineal foot. This price includes the cost of excavation over the quay level, of ground in front of the quay, and of the diversion of the Marina roadway 2,080 feet in length. The blocks were 6 feet long lengthwise of the quay, and weighed, at 15½ cubic feet to a ton, from 48 to 52 tons in the air. The mode of construction of the portion of quay built on the block-system was similar to that adopted for the Deep-Water Quay, North.

DEEP-WATER QUAY, NORTH.

This is 1,421 feet in length, and extends from Penrose Quay to Water Street, Cork. Owing to the possession of the ground having been obtained at different periods, and to special arrangements with the Great Southern and Western Railway Company, it was built in three distinct sections. It was constructed to afford a depth of 20 feet at low-water, as nearly as possible on the existing line of river frontage. The works were authorized by the Cork Harbour Act, 1877.

The substructure for the entire length of 1,421 feet, with the exception of 30 feet at the Water Street termination of the quay laid with concrete in position, consists of three concrete blocks each 6 feet long lengthwise of the quay, weighing from 35 to 49 tons each. The blocks were made on a block-wharf on the opposite side of the river, and were transported and laid by a sheers-float built for the work.

The concrete in the blocks was in the proportion of 7 to 1 by measure, namely, 5 parts of ballast as dredged from the river, 2 parts of limestone broken to pass through a 3-inch ring, and 1 part of Portland cement.

The foundation was gravel and sand, for the most part fine and compact. The superstructure was constructed of dressed limestone, ashlar on face, laid in regular courses, and backed with 6 to 1 concrete. Displacement stones, forming from ⅓ to ½ of its bulk, were laid in the backing. The wall was coped with blocks of Cornish granite, 5 feet deep by 2 feet in height.

One-half the length of this quay was built to section, Plate 11, Fig. 4, with two bottom blocks and one block on top; and the other half to section, Fig. 5, with three blocks in height. The average progress of the work was about 400 feet per annum.

The block-wharf (Figs. 10 and 11), a timber flooring resting on short bearing-piles, was 4 feet 6 inches above low-water of spring-tides, which level admitted of the blocks being made in advance of the rising tide. Each block was allowed twenty-eight days to set before being removed from the wharf.

The concrete for the blocks was prepared in one of Stoney's semi-cylindrical mixers with revolving blades, which delivered into small wagons running on a gantrey over the block-wharf, and the concrete was tipped directly from these wagons into the block casings. The blocks when being removed were suspended by four stirrup-rods, in which rested two small wrought-iron girders running the full breadth of the block. These girders were placed in recesses constructed at or near the bottom of each block, and were withdrawn when the block was laid.

Vertical recesses, 10 inches by 5 inches, were left in the sides of the blocks for the stirrup-rods, so that none of the suspending appliances projected outside them. When the blocks were laid in position, the recesses in each block corresponded with the recesses in the adjoining block, forming vertical spaces 10 inches square, which admitted of dowelling the blocks together. They were filled with solid stone dowels, in lengths of 3 to 4 feet, for the entire height of the block.

The sheers-float, by which the blocks were lifted, transported to the site of the quay, and lowered, was calculated to lift blocks up to 50 tons weight. The plan of the hull was V-shaped, having a great width at the bow, gradually narrowing towards the stern, thus affording great buoyancy under the sheers and carrying the counterpoise as far back from the centre of displacement as possible.

The lifting-gear was a screw-and-worm wheel, actuating two pitch-chain wheels on the same shaft. It was driven by two horizontal direct-acting engines with 12-inch cylinders and 12-inch stroke. The pitch-chains were tested to 24 tons each, and were of sufficient length to admit of a block being lowered 27 feet below the bottom of the float. The vessel was divided into six separate water-tight compartments by two fore-and-aft bulkheads, and one thwartship bulkhead. The sheers were built in as part of the fore-and-aft bulkheads, were carried up 13 feet over the deck, and overhung the end of the vessel 7 feet 4 inches to the centre of the hanging sheaves. Water-tanks were adopted for counterpoise. They had a total capacity of 83 tons, and gave a displacement of 8·736 tons per foot of immersion. The displacement of the remainder (forward section) of the vessel per foot of immersion was 27·01 tons. The machinery worked with great steadiness and regularity, and one man had complete control of it. The vessel, which cost £2,932, was sold on the completion of the works for £1,450.

The block was lowered into its bed by the machinery, the buoyancy of the float being sufficient to admit of this being done without emptying the tanks; this was a matter of some importance, as occasionally it was found necessary to lift a block for a second time, to adjust the bed or for the purpose of getting the block into exact position.

The foundation was excavated by a dredger to within about 2 feet of the proper depth. The layer of 2 feet left by the dredger was cleared out and the foundation levelled by divers working in helmet and dress.

A rectangular frame, a few inches larger than the base of the block, constructed of angle-iron, was first lowered into position. This frame was sunk to the required depth by excavating underneath it, and was carefully brought to the proper level for the foundation of the block by means of soundings from above, which were signalled to the divers. The ground in the centre of the frame was then cleared away and adjusted by an iron straight-edge moved along the sides of the frame. The wall was backed with gravel dredged from the river, supplemented by quarry rubbish from the land side. The block projection in front at the base of the superstructure was sloped off, and American elm fenders were fixed 50 feet apart to keep vessels off the projection.

The blocks, both in this and in the south quay, were laid with facility and without accident. Hydraulic travelling-cranes have been erected on the Deep-water Quay, North; the wall has proved satisfactory in every respect, and has not shown any signs of settlement. A length of 761 feet of this quay was built without the intervention of a contractor, and 660 feet under partial contract.

The total cost was £55,630, or £39 3*s*. per lineal foot.

From data obtained in its construction, the Author estimates in detail the cost of similar work as follows, including contractors' profit:—

				Per Lineal Foot.		
	£.	s.	d.	£.	s.	d.
Earthwork—						
Preparatory excavation of ground, 71 cubic yards, at 1*s.*	3	11	0			
Excavation of foundation by divers, say 23 feet by 2 feet = 1·7 cubic yard, at 27*s.*	2	5	11			
Refilling back of wall on completion of quay, 47 cubic yards, at 1*s.* 6*d.*	3	10	6			
				9	7	5
Blocks—						
Concrete in blocks, on wharf, 7 to 1 (cement 48*s.* per ton) "1 ton of cement to 6 cubic yards of block," 12 cubic yards, at 18*s.*	10	16	0			
Sheers-float, lifting and laying blocks, at £3 per block (including wages when idle), equal to 12 cubic yards, at 2*s.* 6*d.*	1	10	0			
Filling dowels and adjusting upper blocks, at 20*s.* per block	0	10	0			
				12	16	0
Superstructure—						
Ashlar facing (say 2 feet deep) 15 square feet, at 6*s.* 3*d.*	4	13	9			
Concrete backing, 6 to 1, 3·21 cubic yards, at 18*s.*	2	17	9			
Granite coping, 10·76 cubic feet, at 4*s.*	2	3	5			
				9	14	11
Surface metalling (80 feet by 9 inches) 2·22 cubic yards, at 4*s.* 6*d.*	..			0	10	0
				£32	8	4
Contingencies 10 per cent.	..			3	4	10
Plant—						
Sheers, float, and spare gear	3,095	0	7			
" " " ballast	10	6	10			
Four wrought-iron girders for blocks, at £4 17*s.* 6*d.* each	19	10	0			
Stone-breaker (15 inches by 7 inches)	157	13	9			
8 HP. portable engine	244	15	0			
Diving apparatus	390	5	11			
Rails	39	10	2			
Timber in block-wharf, divers' barge, &c.	1,018	1	11			
Iron in block-wharf and sundries	50	11	7			
4-ton hand travelling-crane	153	4	8			
3-ton steam-crane	343	0	0			
Total cost	£5,522	0	5			
Credit one-third for value when released	1,840	13	5			
	£3,681	7	0			
Repairs for time engaged (4½ years) at 5 per cent.	782	5	7			
	£4,463	12	7			
£4,463 12*s.* 7*d.* ÷ 1,421 feet	..			3	2	10
Total per lineal foot	..			£38	16	0

The rates of wages paid per day were: Foreman of works, 7*s.* 6*d.*; mason diver, 10*s.*; labourer diver, 5*s.* 4*d.*; masons, 5*s.* 6*d.*; carpenters, 5*s.* 6*d.*; crane-men, 4*s.*; and labourers, 2*s.* 4*d.*

The works were completed in June 1883. The contractors for the portion built under partial contract were Messrs. H. and J. Martin, of Belfast. The amount of their contract was £18,000 and the work was finished six months before the time specified.

The blocks were well laid, and the provision in the specification "that the intervening spaces between blocks should not average, in entire length of quay, more than 1½ inches" was carried out.

The Resident Engineer on the foregoing works was Mr. Francis R. Mahony, Assoc. M. Inst. C.E.

DEEP-WATER QUAY, QUEENSTOWN.

This quay was built in front of the Great Southern and Western Railway Company's terminus at Queenstown, under the provisions of the Cork Harbour Act, 1877, and was constructed to section, Fig. 6 and Plan Fig. 8*a*, to give a depth of water alongside of 24 feet at low-water ordinary spring-tides.

Owing to the position of the site, the nature of the foundations, the steep slope seaward of the underlying rock and its irregular depth, the quay at one end being founded (back of blocks 8 feet, and front, or toe, 16 feet) above the surface of the rock, and at the other end resting in part on the rock itself, the Author was unwilling to undertake the sole responsibility of the design, and asked his Board for assistance in the preparation of the plans. Accordingly, Mr. B. B. Stoney, M. Inst. C.E., was consulted, and the design, as carried out, is mainly due to him. The quay-wall, for 28 feet in height, is constructed, to 2 feet over low-water level, of concrete blocks (two in height) 8 feet long each, lengthwise of the wall. These blocks weighed 108 and 120 tons each. The top blocks were dowelled together by cement put down in sacks, in recesses constructed in the blocks for that purpose. The bottom blocks were not dowelled.

The section of quay was increased at the returns at each end, which are circular on face, the blocks being tapered to the shape of arch stones. These returns, always weak points, were further strengthened in the east return (Fig. 9), which was the sharper of the two, by a special block 12 feet high, fitting against the backs of the arched or tapered blocks, with concrete, in sacks, on top; and in the west return by concrete, in sacks, deposited at the back. The masonry of the superstructure was of the same description as at

Deep-water Quay, North. In January 1878 five tenders were received for the construction of the quay, exclusive of the road approach, on the conditions that the foundations should be dredged, without charge to the contractor, to about 23 feet below low-water, and that the filling at the back of the quay-wall should be supplied to him by the Commissioners free of charge. These tenders varied from £27,322 to £44,000. The lowest, that of Mr. John Delaney, of Cork, was accepted.

Owing to delay in obtaining possession of the foreshore and other causes, the contractor's tender was increased to £28,688. The work was carried out under the Author's direction, the Resident Engineer being Mr. Henry Keating, M. Inst. C.E., and the work was completed on the 17th of January, 1883.

The sheers-float, for laying the blocks, cost about £5,000. The hull was 90 feet in length, 32 feet wide, 9 feet 10 inches deep fore, and 13 feet 10 inches aft.

The sheers fixed on the fore end carried a pair of powerful pulley-blocks and chains. Six water-tanks were constructed at the after end of the hull, capable of holding 150 tons of water, to act as a counterbalance. The machinery consisted of a locomotive boiler and a pair of 8 HP. horizontal engines connected by gearing to two drums, each 7 feet in length by 4 feet in diameter, and chains passing over the two pulley-blocks attached to the upper part of the sheers. The lower pulley-blocks were fitted to massive forged beams, the ends of which were slotted out to receive the lifting-bars. Each block was suspended by four of these bars. Cast-iron plates were fixed in the bottom of the concrete blocks, with rectangular holes to receive the T heads of the lifting-bars. The rods were dropped through with the heads in the direction of the length of the holes in the plates, and were then turned one-quarter round to admit of the T bearing on the plate. This floating-sheers performed its work satisfactorily without accident, and one hundred and seventy-two blocks were lifted and laid by it. The position of the quay necessitated the construction of an expensive road-approach, to connect it with the public road. When the superstructure of the quay was nearly completed to the level of the coping, and the back of the wall had been filled in to the level of about 4 feet over the top of the blocks, a slight settlement appeared in the eastern return. It increased for several months, and caused some uneasiness, and was, the Author believes, due to an unequal yielding of the foundation. The settlement appeared on the return, and on the front face, for about 50 feet from the angle. At one point the superstructure was fractured through from front to back for the full height, having opened about ⅝ inch, and the batter of the wall was reduced from 1 in 12 to 1 in 14. The wall sank 9 inches in the neighbourhood of this crack, the depression gradually diminishing on each side, the total length affected being about 100 feet. The superstructure was strengthened for 100 feet in length by an extra thickness of concrete, mainly with the object of weighting the back of the blocks, and the wall was then carefully backed with rubble filling. No further settlement of any consequence took place; but the tendency to move, as evidenced by the necessity of frequently re-pointing the cracks, did not entirely cease for five years after the first appearance of the settlement.

The total cost of the quay was:—

	£.	*s.*	*d.*
Contract, and extra works	30,499	3	9
Filling back of wall, &c.	3,689	0	3
Total	34,188	4	0

The cost of the road-approach to the quay, under a different contract, was £3,290 9*s.* 10*d.*

The length of the quay on the front face is 600 feet; the equivalent length of returns, say, 87½ feet. The substructure in these returns was reduced by steps as the blocks approached the land.

The cost of quay per lineal foot was: $\frac{£34,188\ 4s.}{687\frac{1}{2}} = £49\ 14s.\ 7d.$

The American mails are now landed at, and despatched from, this quay, and Her Majesty's troops are embarked from the railway into troopships lying at the quay.

The Paper is illustrated by three drawings, from which Plate 11 has been prepared.

(*Paper No. 2426.*)

"On Building in Earthquake Countries."

By John Milne, F.R.S.

The information contained in the following Paper is based upon observations, made by the Author, upon buildings which have been shattered or thrown down by earthquakes in Manila and Japan, descriptions and photographs of destruction caused by earthquakes in Italy, California, and other countries, numerous experiments which the Author has conducted upon earthquake motion in various parts of buildings, experiments upon the surface and beneath the surface of the ground, and by the perusal of an extensive literature relating to building in earthquake countries.[1] This latter includes governmental regulations respecting building in such countries. Other information has been obtained by direct communication with residents in almost all the earthquake-shaken countries in the world. Much of the Paper may therefore be regarded as a compilation; a certain portion, however, is the result of original observations.

In order to make this Paper a sequel to a Paper on the same subject, contributed to this Institution in 1885,[2] the Author has considered it advisable to give the following brief explanation of the nature of his first Paper, which chiefly dealt with principles to be followed when constructing buildings in earthquake countries. The principles enunciated in the first Paper were:—1. To select a site for a building, and to give it such foundations that it should receive the least possible quantity of motion. These two subjects are again referred to under the headings "Choice of a Site" and "Foundations." 2. To construct a building in such manner that it shall be able to resist best the particular kinds of stresses which are the results of earthquake motion. To do this, amongst other things, it must be remembered that these stresses are in great measure applied horizontally, and therefore, for example, archwork

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[1] Appendix.

[2] Minutes of Proceedings Inst. C.E., vol. lxxxiii. p. 278.

is unsuitable to withstand earthquake motion. Again, it should be remembered that it is undesirable to couple together, unless they are coupled so that they move as a whole, parts of a building that are not likely to synchronize in their movements. By neglecting this principle, brick chimneys are often destroyed when they pass through a wooden house. Lastly, centres of inertia should be kept low; it is therefore undesirable to give top weight, as in a roof or in the coping-stones of chimneys. These matters are again referred to, but with greater detail. The various points raised in the discussion on the first Paper, to which the Author was unable to reply owing to his absence in Japan, are referred to under the headings to which they belong.

1. Choice of a Site.

A good site may often be obtained in a given city by taking advantage of the results of experience. Thus, in the Ansei earthquake in Tôkiô, it was shown that the greatest destruction took place on the low soft ground, while on the high hard ground the destruction was relatively small. Observations of this nature were made in 1883, at Casamicciola, and then were taken advantage of by the Government when laying out the site for a new town. The occasions when observations like these have been forced upon communities have been very numerous; as, for example, at Lisbon in 1755, Port Royal in 1692, Belluno in 1873, in Calabria in 1783, San Francisco in 1868, Talcahuana in 1835, and in Messina in 1726.

Although it is a general rule that hard high ground is best, it must not be overlooked that there have been exceptional cases where buildings in such localities have suffered, as in Yokohama in 1880, and to a certain extent in Calabria in 1783.

In Tôkiô, as the result of personal feelings, it has been shown that earthquakes are more often noticed on high ground than upon low ground. Instrumental observations, so far as they have gone, and the results of experience in 1885, have, however, proved that the most destructive motions have been experienced on low ground.[1]

The best sites in a city may be determined, should it be thought advisable, by means of a specially organized seismic survey, which

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[1] "Distribution of Earthquake Motion in a Small Area." By J. Milne. Transactions of the Seismological Society of Japan, vol. xiii.

involves placing a number of similar seismographs throughout the area to be investigated, and a comparison of the records they furnish. By doing this a seismic survey may be made for a small piece of ground, say ¼ square mile or less in area. Such a survey was made of the compound of the late Imperial College of Engineering, now the Gakushuin, in Tôkiô. The results proved that of two similar houses on that compound, at a distance of less than 800 feet apart, one of these houses might be destroyed by a given earthquake and the other suffer little if any damage. Until this survey was made, it was not suspected that the difference in motion on two sides of that particular piece of ground could be so pronounced. Very wet ground, or ground that is marshy, notably forms a bad foundation. Steep sloping ground is also bad, the alluvial material resting on such a surface often sliding downwards, much in the same manner as tiles may slide from a steeply-pitched roof. The sliding, or tendency to slide, is in all probability aggravated when the surface is loaded by a building.

The upper edges of cliffs and scarps, where the motion of the free face of the cliff or scarp is naturally large, are also dangerous situations, and these more especially when the strata dip outwards. Mr. R. Henry Brunton, when discussing the Author's first Paper, regretted that the observations respecting a seismic survey had not been over a more extended area. Observations have been made, and continue to be made, on an area embracing the whole of the Japanese empire. To do this there are about six hundred and fifty stations recording every year about five hundred different disturbances. The results are of considerable scientific importance, showing which portions of the empire are most shaken, and how seismic activity shifts from point to point. Their practical value, as compared with the records showing the differences in movement in an extremely small area, are, however, relatively small. If public buildings have to be erected in a city, surely it would be well to place such buildings in positions where they would receive the least amount of motion, and a seismic survey must certainly indicate where such places are to be found. Mr. E. G. Holtham concluded that but little importance could be attached to seismic surveys. This conclusion was based on the opinion that the diversity in the records published in the Author's first Paper are so slight, that they might even occur with simultaneous observations. Had Mr. Holtham referred to the description of the seismographs, and, to the tests to which they have been subjected, he would have seen that when two seismographs are placed side by side they practically give the same diagram; but, when they are separated from each other, say by 100 feet, they give different diagrams. Further, if a seismograph be placed on a table and the table shaken, the diagram of the motion is practically identical with the motion of the table, recorded by taking advantage of a steady point outside the moving table. For such earthquakes as are experienced in Japan, and some of them bring down chimneys and unroof houses, seismologists on the spot have every confidence as to the accuracy of the records furnished by their instruments; the difference of a few millimetres of motion, or the fraction of a second in period, may determine whether damage will occur or not. The Author is of opinion that an earthquake with a 25-millimetre (0·984 inch) amplitude and an ordinary period would wreck the half of London.

Although Mr. Brunton says that soft marshy ground may tend to absorb earthquake motion, marshy ground appears to be one of the worst places for building on. This is not a matter of "theory," as supposed by Mr. Brunton, but it is a matter of direct observation. Special experiments in Japan have repeatedly shown that although the period of motion is increased in soft ground, the advantage thus gained is more than counterbalanced by the enormous increase in amplitude, and marshy ground ought therefore to be avoided. This has been so thoroughly recognized, that the Building Regulations of Manila, respecting structures to resist earthquakes, make special reference to foundations on soft ground. In Ischia certain tracts of soft ground are marked off by the Government as unsuitable for buildings of any description.

2. FOUNDATIONS.

As a result of observations made in a pit about 10 feet in depth, it was found that the motion at the bottom of the pit was, in strong earthquakes, very much smaller than upon the surface. These observations led to the conclusion that great advantages might be gained by giving a building a deep foundation, this advantage being increased if the building rose freely, as in a house with an open area and a basement. That, at least, there is no harm in such a structure is attested by the fact that, in all earthquake countries under building regulations, cellars or basement archwork is recognized as admissible. That relatively little motion enters a building with such foundations is also attested by the fact that in cellars vaulting is allowed, whereas for stories above the ground-floor it has invariably been suppressed. The Author's own experiments in this direction gave a measurement of the relative motion above and below ground, showing that deep foundations were not simply without danger, but that they might be advantageous. As, however, the experiments have only been made at one point, and as they are of so much importance to builders, they should be repeated.

The Ischian regulations provide that buildings should be founded on the most solid ground. If, however, the ground is soft, a platform of masonry or cement should be formed, which, for a one-story building, must be 0·70 metre (2·30 feet) thick, and for a two-story building, 1·20 metre (3·94 feet) thick. This platform must extend from 1 to 1·50 metre (3·28 to 4·92 feet) beyond the base of the building. In Manila it is stipulated that the foundations must be able to bear at least twice the weight that is to be placed upon them. When the soil is bad, it must be piled or consolidated by a bed of hydraulic concrete, and the foundation of a building must, so far as possible, be made continuous.

Another method of minimizing the motion received by a building is to give it free foundations. As an example of this, the Author mentions a room attached to his own house, which rests at each of its pillar-like foundations upon a layer of ¼-inch cast-iron shot, between two iron plates. Short rollers, placed at right-angles, might be equally effective. This building has stood for many years. It has not been disturbed by typhoons, and at the time of an earthquake a seismograph inside the building shows, relatively to one outside, but little motion. Cast-iron balls or shot, even if they are only 1 inch in diameter, cannot be used; they are wanting in frictional resistance, and the building is therefore subject to movements produced by winds and other causes. The Author does not bring forward this building as an example to be followed in ordinary practice, but only as an illustration of a principle which may have practical applications.

The ordinary Japanese dwelling-house rests loosely on the upper surface of boulders or stones planted in the soil, and therefore it is difficult to conceive how it can receive the whole of the motion imparted by the shaking ground to its stone foundations. In temples and other large buildings with heavy roofs, which are common in the country, beneath the supporting timbers and the superstructures there is usually a multiplicity of timber-joints, which at the time of an earthquake yield, and therefore do not communicate the whole of the motion from below to the parts above. In the great earthquake of Ansei, in 1855, so far as the

Author is aware the whole of these buildings remained intact. Certain roofs of considerable span, in the engineering college at Toranomon, in Tôkiô, were built so that they rested freely on the supporting walls, the object being that they might remain, so far as possible, resting freely on the wall which moved beneath them. Although they have experienced many tolerably severe shakings, hitherto they have remained uninjured. These examples show, especially for horizontal components of motion, that if a small building is not firmly attached to its foundations, or that if parts of a building have connection between them that readily yield, it is difficult to cause such a building to move or swing, and that by a proper application of this principle, destruction may be, and has been, avoided.

Loose foundations might possibly be employed for small light buildings erected on soft ground. For ordinary dwelling-houses, and especially for heavy structures covering a considerable area, the Author is inclined to the opinion that solid continuous foundations in the hardest ground, and if possible surrounded by a free area, are the best. The objection to loose foundations for a large building is that different parts of the same building do not simultaneously receive momentum in the same direction, and also in severe earthquakes there is an actual wave-like motion of the ground.

In the discussion which followed the Author's first Paper, reference was made to the aseismic tables designed by Messrs. Stevenson to carry the lamps in certain Japanese lighthouses. Similar joints were fixed to two iron lighthouses made in England, but on their way to Japan they were lost at sea. Mr. R. Henry Brunton, who was entrusted with the erection of some of the Japanese lighthouses, gave an example where the chimneys of lamps on one of these aseismic tables were pitched off by an earthquake. In Mr. Brunton's Paper on "The Japan Lights,"[1] it is stated that, after erection, the free motion of the tables occasioned so much inconvenience, that the European engineers then in the Japanese service had them clamped, and the arrangement was not adopted in lighthouses subsequently erected. The Author, who is acquainted with the chief officials in the lighthouse department in Japan, learns that "in 1882, wishing to give Mr. Stevenson's tables another trial, several of them were put in working order. The result was that on March 11th, 1882, at Tsurugasaki, a number of the lamp-glasses on the burners were overthrown. Some time

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[1] Minutes of Proceedings Inst. C.E., vol. xlvii. p. 1.

afterwards a second shock produced a similar effect. At neighbouring lighthouses, two of which are within 8 miles, and not provided with aseismatic tables, no damage was sustained. The shock of March 11th was felt for at least 300 miles along the coast, and its effects at Yokohama and Tôkiô, which are at no great distance from Tsurugasaki, were carefully recorded. I am not aware that any small articles like lamp-glasses, bottles, vases, &c., in ordinary houses were overthrown. The fact that no ill effects occurred at other lighthouses provided with Messrs. Stevenson's tables, like those in the Inland Sea and near Kiushu, must not be regarded as an argument favourable to the tables, inasmuch as the earthquake referred to was not felt in those districts. It may here be remarked that one result of the general seismic survey of Japan shows that aseismic tables are no more required in certain portions of the empire than they are required in England."

As a farther illustration of the manner in which aseismatic tables have behaved, the Author quotes the following translation of a report from the Chief Lightkeeper at Tsurugasaki:—

"'Sir,—On October 15th, 1884, at 4.16 a.m., very severe shocks of earthquake were felt. The aseismatic table was in working order, but the shocks were so violent that fifteen lamp glasses out of the twenty-one in use were upset and broken. The lamps thus stripped of glasses began to smoke. The milled heads of the wick-holders being shaken off, and besides the revolving machine being in motion we had some difficulty in replacing the glasses promptly; however. we managed to put them all in proper order again by 4.21 a.m.—I am, Sir, your obedient servant,' &c. &c."[1]

To these examples others of a similar nature might be added, the conclusion being that aseismic joints, as constructed by Messrs. Stevenson, have proved to be of little value. In his first Paper the Author attributed the invention of the aseismic joint to the late Mr. R. Mallet, the reason for which will be apparent to any one who reads Mr. Mallet's introduction to Palmieri's Vesuvius. The first to propose the use of this joint was Mr. David Stevenson.[2] The only part that the Author has taken in relation to aseismic joints for buildings has been to experiment with them until a practical form had been discovered.

3. ARCH-WORK.

An ordinary arch is undoubtedly stable for vertically applied forces, but for horizontal stresses it is most unstable. Arch-work

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[1] Transactions of the Seismological Society of Japan, vol. xi. 1887, p. 174.

[2] Transactions of the Scottish Society of Arts, 1868, vol. vii. p. 557.

has so often been the cause of ruin, when shaken by an earthquake, that, in Italy and Manila, special rules have been drawn up respecting such structures. Thus in Manila intersecting vaults are not allowed, and ordinary vaults are only permissible when strengthened in a particular manner by iron. In Liguria vaults can only be used in cellars, but even there the rise must be at least one-third of the span. The law of Norcia also only permits the use of arch-work in cellars, and the thickness and method of construction is defined. In Ischia arch-work with a rise of one-third of the span, and with a thickness of 0·25 metre (0·82 foot) at the crown, may be used, but only in cellars.

Speaking generally, the use of arch-work above ground has been prohibited, and if it has existed after an earthquake, all governments who have paid attention to building have ordered its removal. Underground its use is permitted provided the arches are not too flat. This, however, only indicates that the motion beneath the surface is too small to destroy even a bad form of structure, and therefore such a form, if it be underground, is allowable.

In his former Paper the Author has given instances where arch-work in Tôkiô has been cracked by exceedingly slight earthquakes. If, for architectural reasons, it is a necessity that arches should exist, they should not be too flat; they should have a specified thickness, be protected by an iron or a wooden beam, and curve into the abutments. The Ligurian regulations provide that above windows there shall be two iron bars.

4. Doors and Windows.

In the building regulations for Norcia and Ischia, it is stated that openings should be placed vertically above each other. It appears to the Author that if a series of openings like doors and windows in a wall be placed vertically above each other, it is much as if the wall had here and there been built with the joints of a line of bricks or stone continuing above each other, that is the uniformity of the wall has been destroyed by lines of weakness, which will readily give way to horizontally-applied stresses.

The subject is not one of great importance, but the Author inclines to the opinion that the doors or windows in successive tiers ought not to be above each other, but so arranged that lines of openings, when regarded vertically, should be as much broken as possible. To arrange doors and windows so that they may form a ready means of escape is certainly a matter worthy of attention.

An important point mentioned in the Ischian law is the position of doors and windows relatively to the freely vibrating end of a building, the limiting distance being 1·50 metre (4·92 feet). Similar provisions are found in the regulations for Norcia and Liguria. This distance should, if possible, be made to depend upon the materials of which a wall is constructed, its dimensions and the size of the openings.

5. Chimneys.

An important point, which constructors should keep before them, is to avoid coupling together two parts of a building having different vibrational periods, or else to couple them together so securely that they shall move as a whole. In Europe the first writer who recognized the fact that builders often allowed one portion of a building to destroy another, in consequence of their non-synchronism in vibration, was Bertelli, who mentioned the matter in 1887. The same subject has, however, been written about, experimented upon, and emphasized in Japan since 1880. In that year, most of the wooden bungalows in Yokohama lost their brick chimneys, in consequence of the wooden framing of the house swinging against them and cutting them off. One example of the absurdity of giving support to a solitary chimney, by attaching it in any way to a building, was given by the Author in his first Paper. By itself a chimney may stand; but, when partially attached to a house, the house and the chimney are mutually destructive.

The rules regulating the construction of chimneys are but few. The Ischian law states that they should be isolated from the walls; that of Liguria that they should not be in the walls, not connected with the building, and low. Chimneys not being much required in Manila, nothing is said about them. Experience in Japan has taught householders to build their chimneys as short and thick as possible, to allow them to pass freely through the roof, and not to load them with heavy coping stones.

After the experiences of 1879 and 1880, many of the residents in Yokohama materially altered the form of their chimneys. In 1887, these buildings did not suffer, the buildings which did suffer chiefly being those put up subsequently to 1880, and without any regard to the experience of previous years.

6. Connection between different Portions of a Building.

This leads to a consideration of the advantages to be gained by tying the different parts of a building together so that they shall vibrate as a whole. Since time immemorial buildings have been tied together with iron or with wooden rods; but some time previous to 1868, when San Francisco was shaken, a patent known as the Toye patent was taken out to improve the construction of sea-walls. This was made to apply to land structures. The City Hall and other buildings in San Francisco are built upon this plan, which consists in tying together the walls at each floor by transverse and fore and aft rods of steel or iron. A plan similar to this is that of Mr. J. Lescasse.[1] It has been applied to several buildings in Tôkiô and Yokohama.

For such earthquakes as these buildings have experienced, excepting on one occasion when the chimneys of the German Hospital in Yokohama were more or less injured, they have stood well. This system, however, requires to be thoroughly executed; for if the rods be too few, or if the bearing surfaces be too small, rather than support a building they accelerate its destruction, especially at the points of contact. Such buildings, partly for this reason and partly on account of their expense, are not looked upon with favour in Italy. The Ischian law specifies that if iron bands or chains are used they must act upon a large surface.

7. Roofs.

The advantage to be gained by making the upper portions of any structure light are very great. When a building with a heavy roof is suddenly moved forwards, the roof by its inertia tends to remain at rest. The result of this is conducive to a fracture, between the lower part which has been removed quickly, and the upper part which has tended to remain at rest. In building regulations special reference is made to roofs, which must always be light, the material recommended being iron or zinc or felt, ordinary tiles being only permissible for buildings one story high, and not for habitations. Certain kinds of tiles have sometimes been regarded as permissible; but these require to be properly secured, and it is specified that in such cases there

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[1] Mémoires de la Société des Ingénieurs Civils, 1877, p. 212.

shall be a floor of planks above the ceiling. Tiles require to be especially well fastened near the eaves.

The difficulty with roofs made of sheet metal is, first to secure them from being disturbed during severe gales, and second, to protect the interior of the house from heat. In Manila the first end is accomplished by a system of bolting, whilst the latter is attained by a series of false ceilings.

The tie-beams of trusses should extend at least two-thirds across the thickness of the wall, and not over the whole thickness, and these rest upon wall-plates. The form of truss recommended in Manila is the one with a central post (king-post). For spaces greater than 7 metres (23 feet) iron should be used, and trusses must be so placed as not to act upon weak points in the walls.

The Ischian law does not prohibit the use of flat roofs (*terrazzo*), but it provides that the framing of the same shall be strong and covered with materials which are fairly light. The Commission, who reported to the Government, however, condemned such roofs.

8. WALLS.

Walls, like chimneys, should be light and strong. If heavy, and especially if loaded in their upper parts by copings and balustrades, they may be fractured and shattered by their own inertia. The height to which walls may be taken with safety depends upon the material of which they are constructed, the nature of the roof, &c. In Ischia it was suggested to limit buildings to two stories, or a height of 7·5 metres (24·6 feet). The regulations, however, give 10 metres (32·8 feet) as a limiting height, and, if they must be of simple masonry, of tuff to a height of 4 metres (13·12 feet), with a thickness of 0·70 metre (2·30 feet). The committee suggested that external walls should be at least 0·30 metre (0·98 foot) in thickness, and that their uniformity should in no way be broken by openings for chimneys, pipes, &c.

The Ligurian regulations allow three stories above the cellar, and a height of 15 metres (49·2 feet). The walls, if not built on the barrack system, should be at least 60 centimetres (23·6 inches thick), and have a batter of one-twentieth of their height. The Norcian regulations allowed two stories above the cellar and a height of 8·5 metres (27·88 feet). If a third story existed it was to be destroyed. The walls were to be thicker than ordinary, and their thickness was to vary with the material employed, and the height of the structure.

In Manila masonry walls of ordinary dwellings only reach the first story, the upper story being of timber. The walls for public buildings, however, may be higher. The regulations specify that the upper walls must not rest on a floor.

The length of a wall should not exceed twice its height unless supported by a buttress. The latter might be used at intervals not greater than twice the height of a wall. Its thickness must be one-fifth of its height. Outside walls, transverse walls and buttresses, must be well united, while the corners of buildings should be supported by buttresses.

It would appear that the system of building with an upper story of wood resting on, and not built into, the supporting wall, and a light roof ought to do much towards insuring the stability of a building. The weight of ordinary masonry may be reduced by the adoption of hollow bricks.

9. BALCONIES AND CORNICES.

In Ischia it was suggested that balconies shall not project more than 0·60 metre (1·97 foot) beyond the wall, and should be so constructed as to form a part of the wall.

The regulations provide that cornices shall not project more than 0·30 metre (0·98 foot) beyond a wall.

The Ligurian regulations provide that cornices shall not project beyond the thickness of the wall to which they are attached. Roofs may not rest on cornices. Stone consoles must run through the wall to which they are attached. In Manila the regulations require that the balconies shall rest on the prolongation of timbers of the upper floor, otherwise a special form of construction is required.

Many of the balconies, or upper verandas, seen by the Author in Manila, were without support on their outer sides. In such instances they act as loaded cantilevers, which, either for horizontal or for vertical motions of the building, must cause considerable stress at their points of junction with the supporting wall. A careful examination of several hundred brick houses in Tôkiô showed that the walls were usually cracked at the points where they were entered by the beams supporting a balcony, notwithstanding that the same balconies were supported along their outer face by vertical pillars rising from the ground. The Author's opinion is that balconies in any form are objectionable features in a building constructed to withstand earthquakes.

10. SHAPE AND ORIENTATION OF BUILDINGS.

In Liguria and Ischia, the regulations provide that a building shall be rectangular in plan, and as nearly as possible square. Churches should be small, and of the basilic form, with three naves, and iron columns between the naves. The Norcian regulations also recommend a square form.

In Ischia it was suggested that buildings should be placed so that the direction of the principal motion they were likely to receive should be along the diagonal of their plan. A result like this might be obtained by laying out the streets and roads in proper directions. Rossi suggested that the most resistant sides of buildings should be placed at right-angles to the nearest line of volcanic fracture, he holding the opinion that earthquake vibrations are propagated normally from the lips of such fractures.

The suggestion that buildings should be on a rectangular plan, or simple in shape, is worthy of consideration. It would certainly seem that such buildings would be subject to less destructive stresses than those largely built up of wings and other projecting parts, no two of which could be expected to vibrate in unison.

Whether any great good may be gained by giving proper orientation to a building is not certain. In Tôkiô walls extending in certain directions have been cracked more than others, and at the times of great earthquakes the destruction has been greater in streets running in a particular direction rather than in other directions. Streets ought to be wide, inasmuch as they would then form a refuge from falling debris.

11. FLOORS.

It was suggested in Ischia that floor-joists should rest with their whole thickness on the walls. If possible, joists should cross each other at right-angles, and the floor-planking be laid diagonally.

Bertelli proposes a system of flooring of iron beams connected by brick vaulting, or in place of this ordinary joists and planking. The beams on one story should be at right-angles to those on another. In all cases the joists are to extend completely through a wall. This regulation is also contained in the Norcian edict.

From these notes it appears that the intention of the authors of the regulations has been to utilize the floors to bind the buildings together as a rigid whole, and allow joists to extend so far into walls that there is no danger of their being drawn from their supports.

12. CEILINGS.

Ceilings should be made in the ordinary manner with lath and plaster, but heavy ornamentation should be avoided.

13. STAIRCASES.

Although staircases, if they are heavy, might prove a danger to walls, their construction has not been regulated by legislature. Bertelli suggests that they should be constructed of pieces bedded in the walls, as in the Tuscan system. If made by vaulting they are dangerous.

14. MATERIALS.

In all regulations special stress is laid on the quality of materials employed, and in all cases it is specified that these shall be of good quality. The Ischian regulations specify that for the principal framework of buildings chestnut must be used. In all cases squared stones are to be employed. The lime must be good, and be properly slaked with fresh water. Below ground hydraulic mortar must be used, and the sand for the mortar must be clean. These matters are treated upon in all regulations. In the regulations for Manila there are special remarks condemning the use of liquid lime, and recommending that stone walls shall be kept wet while the mortar is setting, also that there shall be good bonding, &c.

15. TYPES OF BUILDING.

The type of building most suitable for earthquake countries was discussed at considerable length by the commission summoned after the disaster in Ischia.

The objections to iron buildings chiefly rested on their cost, the difficulty of keeping them cool, and the fact that, as they were a novelty, it might be difficult to get them generally accepted. The commission, however, considered them durable and secure, and recommended that experimental buildings should be erected.

Timber buildings, although sufficiently strong and elastic to resist earthquake motion, and at the same time impervious to heat, have the objection that they are not durable, and are liable to take fire. These objections may to some extent be overcome by the proper application of paints and chemical preservatives. Mixed constructions of iron and timber were not considered to present great advantages over those wholly made of timber.

Buildings may be made of iron or masonry either by covering an iron framework with stone or brick, by building an iron framework inside the masonry walls, or by filling up the spaces between a double metallic framework with hollow bricks or other materials. Such buildings, although good from many points of view, have the drawback that they are exceedingly expensive.

Having considered these types, from which it will be observed ordinary buildings of brick and masonry have been excluded, the committee describes a "barrack" system of building, which is the system particularly recommended for Ischia. Briefly, such a building consists of a timber framework well braced together, the spaces between the timbers being filled up with hollow bricks, or some light material like scoria. The timbering is hidden by rough cast. After the disaster in 1755, such a system was made compulsory in Portugal. A building of this type, which may be ornâmented with an outside covering of tiles, is cheap, impervious to heat, and safe against earthquakes and fires. The suggestion respecting this system of construction was adopted in the regulations issued by the Government.

In the building regulations for Norcia, the barrack system is the one to which preference is given. In the Manila regulations considerable latitude is allowed as to the system of construction; stone walls are thought best, but concrete or brick are also approved of. Although timber offers great resistance to earthquakes, its destructibility by fire, white ants, ordinary rot, and its inability to exclude heat, prevent its recommendation. An iron framework filled in with concrete is spoken of with favour. In the recommendations of a committee appointed to consider building in Manila, stone is suggested for the basement and for the walls of the ground-floor. This, with an upper story of timber, is the type of building common in Manila.

The Military Committee, which was summoned in connection with the destruction in Manila in 1863, pointed out that destruction had occurred in all classes of buildings, but that buildings with masonry supports had suffered more than others. This led to the suggestion that only one kind of material should be used in construction, and that masonry supports should be avoided. Private buildings should be of wood. In all cases the limiting spans of roofs were specified, and that the roofs must be light. Lieutenant-Colonel Cortés, who wrote at some length on structures in earthquake countries, shows that buildings must be light, as well as strong, and this may be obtained by building their parts together, much in the same manner that the timbers of a ship are bound together. Foundations and walls should be continuous. Timber-work and masonry should not come in contact, otherwise they may be mutually destructive.

After criticising the system of building in Manila, and showing how it may be improved, especially with regard to balconies and roofs, Colonel Cortés proposes as a foundation a timber platform, almost on the surface of the ground, from which rises a building with iron or timber framing, footed on a dado of masonry, surmounted by a light roof. The wall-framing may be filled with brick or plaster. Colonel Cortés' descriptions are accompanied by an elaborate series of illustrations.

The Californian system of construction, for which a patent has been granted, appears to be very similar to that proposed by Mr. Lescasse, the essential feature in which is to tie a masonry construction together at each story by a set of iron or steel rods, which run from end to end and from back to front in the interior of the walls of a building. There are also rods running vertically.

From South America but little information has been obtained. In Colombia the smaller houses have been built of thick adobe bricks, while the Spanish have used stone.

In Equador (Quito) occasionally a special earthquake-proof room is built, the walls of which are a wooden framework, filled in with adobe. Many houses which have adobe walls 3 feet thick have only one story, and there are few houses with more than one upper story.

In Venezuela, also, the houses are low. In Mexico and in Bolivia the houses are solidly built, while in Lima certain buildings are constructed lightly, so that they may yield.

From Guatemala (San Salvador) the Author received from Messrs. Clark and Company, contractors, the drawing of a house supposed to be earthquake-proof. The house is of timber, well framed together, and very similar to bungalows built in Japan.

These latter descriptions are particularly meagre; for a full account of the systems to which they refer, it is better to consult vol. xiv. of the Transactions of the Seismological Society of Japan.

16. CONCLUSIONS.

To mitigate the effects of earthquakes, one general conclusion may be drawn from what has been written, namely, that it is essential to select a site where it is known that the ground suffers but slight motion. This is generally hard, high ground. Soft ground, slopes, and scarps should be avoided.

Having obtained a site, one of two general systems of construction can be followed, namely, either to give so much rigidity to a structure that it may be likened to a steel box; or to erect a light building which has so much flexibility that it may be compared to a wicker basket. Both these structures should be light, especially their upper parts.

Buildings of the former class which, from the materials entering into their structure, are unquestionably heavy, include ordinary structures of stone or brick (by preference hollow bricks). These should rise from a deep foundation, have a free basement, walls of unusual thickness, and be well bonded and tied together. The roofs should be light, and the precautions respecting the position and form of openings, the arrangement of floors, roof trusses, and top weight, referred to in the preceding epitome, should be carefully attended to. In this case the strength of the building more than outweighs the ill effects due to its weight. Such buildings are durable, and relatively safe against fire. They are suitable for all climates; but they are, in respect to all other buildings, exceedingly expensive. For this latter reason, this type of structure can only be employed for buildings of importance.

Light buildings, which have sufficient strength and flexibility to overcome effects due to their own inertia when shaken by an earthquake, include nearly all well-constructed structures of wood or iron. The former, however, are neither durable, safe against fire, nor impervious to heat and cold; but these objections may be practically overcome, and wooden buildings are cheap. Iron buildings are relatively expensive, and, without special arrangements, they are too hot in summer and too cold in winter.

A type of building which offers the same advantages as a brick or stone structure against the danger of fire, and in being suitable to resist changes of temperature, and which is also much cheaper, and at the same time safe against all ordinary earthquakes, is the barrack system so strongly recommended in Italy. The framing may be of wood or iron, while the filling-in which forms the walls, which ought to be as light as possible, may consist of hollow bricks or a concrete of light material. For this latter purpose, in Japan, a concrete might be made of the pumiceous light scoria, of which there is an abundance. The Author would also call attention to the possible employment of cylindrically-formed or drain-pipe shaped bricks, such forms being stronger than bricks of the ordinary rectangular section.

In all these buildings, whether they be of masonry, iron, wood, or built according to the barrack system, the roofs must be light, openings must be in proper positions, walls must be of moderate height; while floors, trusses, balconies, and the like, must be constructed in accordance with the previous suggestions. Ordinary structures of brick or stone are usually bad, while timber structures with a masonry front are worse. To resist earthquake motion, lightness and strength are essential, and, if possible, a certain elasticity. Weight, unless it is accompanied by great strength, is a quality to be avoided.

For buildings of importance, the Author suggests the use of brick. Let the buildings be placed in good situations, the brickwork well bonded and unusually thick, and let them rise from deep foundations. Roofs should be light. For ordinary buildings, unless the barrack system be adopted, the Author suggests that, for a country like Japan, frame buildings should continue to be used. To improve them, they require more diagonal bracing, lighter roofs, and some protecting covering against fire. In carrying out these suggestions, the conclusions respecting general principles, and the details of construction arrived at in the preceding epitome, must not be overlooked.

In the discussion on the Author's former Paper, Mr. R. Henry Brunton remarked that, " The decision at which he arrived in his designs for the Japanese lighthouses was to follow the principles enunciated by Mr. Mallet, and Professor Palmieri, to give the buildings weight and great inertia, coupled with a good bond between their various parts. . . . That indicated the principle followed by him in the construction of the Japanese lighthouses." If buildings have great weight they certainly have great inertia, and as it is the inertia of certain portions of buildings which render them self-destructive, the Author cannot share Mr. Brunton's opinion. Rather than giving a building great weight he would be inclined to make it very light. Mr. Henry Dyer's opinion, that Japanese structures are exceedingly ill adapted to resist earthquake-motion, is one with which the Author cannot concur. In 1880 and 1887 ordinary Japanese buildings resisted earthquake-motion much better than ordinary European-built bungalows and framed structures with a stone or brick facing. The Japanese buildings which suffer most are the fire-proof stores which, Mr. Dyer remarks, generally withstand earthquakes.[1] Mr. Dyer states that substantially-built buildings of the Im-

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[1] Transactions of the Seismological Society of Japan, vol. i. part 2, and vol. xi.

perial College of Engineering in Tôkiô have suffered but little. Cracks, however, have been found; and at the time of earthquakes these have been observed to open or shut, and occasionally to extend in length. Mr. Dyer's opinion is that the cracks, which chiefly occur in the Dormitory and Museum at the College of Engineering, were not formed by earthquakes but by bad foundations. If the foundations had been better, possibly the cracks might not have occurred; but that does not alter the Author's opinion, which is, that they were caused by earthquake movements acting upon the weaker parts of the buildings. On the 15th of February, 1887, the Author's own house, which may be included in the buildings referred to by Mr. Dyer, was cracked from top to bottom by an earthquake, and many stones forming the corners were displaced $\frac{1}{4}$ inch. The building is of brick with a stone foundation, stones at the angles, and an internal wooden frame. At the workshops at Akabane, in Tôkiô, which buildings are referred to by Mr. Dyer as satisfactory structures, one of the chimneys was, in 1880, cracked by an earthquake, and had to be strengthened by iron bands. Mr. E. G. Holtham, when discussing the Author's first Paper, remarked that in Japan timber-framed houses faced with stone are considered earthquake-proof. As a matter of fact, although many such buildings exist in Japan, it has often been observed that they have been seriously damaged while other buildings have escaped. They are one of the worst types of buildings for an earthquake-country. The Author has cited the destruction which took place at his own house in 1887, and Mr. Holtham has referred to the effects produced in 1880 upon the two most important railway stations in Japan, which unfortunately have been built upon this undesirable system.

[APPENDIX.

APPENDIX.

Principal works from which information has been drawn in preparing the Paper "On Building in Earthquake Countries."

1. Relazione della Commissione per le prescrizioni edilizie dell' Isola d'Ischia, instituta dal Ministro dei Lavori Pubblici (Genala) doppo il terremoto del Luglio 1883. Roma.
(Report of the Committee appointed to propose building regulations for Ischia after the earthquake of 1883.)
2. Regolamento edilizio della città di Norcia del 28 Aprile 1860.
(Building regulations for the town of Norcia, 28 April, 1860.)
3. Regolamento edilizio per i comuni dell' Isola d'Ischia, danneggiati dal terremoto del 28 Luglio 1883.
(Building regulations for the communes of the Island of Ischia damaged by the earthquake of July 28th, 1883. Issued by the Minister of Public Works.)
4. Norme per la construzione e il restauro degli edifici nei comuni Liguri danneggiati dal terremoto del 23 Febbraio 1887.
(Rules for the construction and repairs of buildings in the Ligurian communes damaged by the earthquakes of February 23rd, 1887.)
5. Decreto e regolamento per l'esecuzione dell' Articolo 7 della Legge 31 Maggio 1887.
(Decree for the enforcement of Article 7 of the law of May 31st, 1887.)
6. Against the destructive effects of earthquakes, by Father Bertelli, Collegio alla Quercia, Florence. An extract from "La Nazione," June 10th, 1887.
7. Reglas para la edificacion en Manila, dictadas a consecuencia de los terremotos de los dias 18 y 20 de Julio 1880.
(Building regulations for Manila, drawn up in consequence of the earthquakes of the 18th and 20th July, 1880. Issued by the Department of Public Works.)
8. Informe sobre el sistema general de construcciones de los edificios públicos y particulares en estas Islas. 1863.
(Report on a general system of construction for public and private buildings to be adopted in the Philippine Islands. Drawn up by the Military Committee in Manila. 1863.)
9. Los terremotos sus efectos en las edificaciones y medios practicos para evitarlos en lo posible. Memoria escrita por el Comandante de Ingenieros del Ejército D. Manuel Cortés y Agulló, en 1873 y revisada en 1880. Manila.
(Earthquakes, their effects on buildings, and practical means to avoid the same as far as possible, by Lieutenant-Colonel Don Manuel Cortés y Agulló. 1873 and 1880.)

10. Étude sur les constructions Japonaises et sur les constructions en général au point de vue des tremblements de terre, &c. Par M. J. Lescasse. 'Mémoires de la Société des Ingénieurs civils,' séance du 6 avril 1877, page 212.
    (On Japanese buildings, and on constructions in general with reference to earthquakes. By J. Lescasse. 'Memoirs of the Society of Civil Engineers of Paris.' 1877, page 212.)
11. Constructive art in Japan. By R. H. Brunton. 'Trans. Asiatic Soc. of Japan,' ii. and iii., part 2.
12. Some remarks on construction in brick and wood. By G. Cawley. 'Trans. Asiatic Soc. of Japan,' vi., part 2.

In addition to the above works, which specially treat of construction in earthquake countries, through the kindness of his friend Mr. T. B. Clarke Thornhill, Her Majesty's Secretary of Legation in Tôkiô, the Author has received communications on the subject of building from the British Legations in Bogotà, Quito, Caraccas, Mexico and San Salvador.

(*Paper No. 2457.*)

"A Method of taking the Temperature of the Cylinder Walls of a Steam-Engine at Different Depths in the Metal."

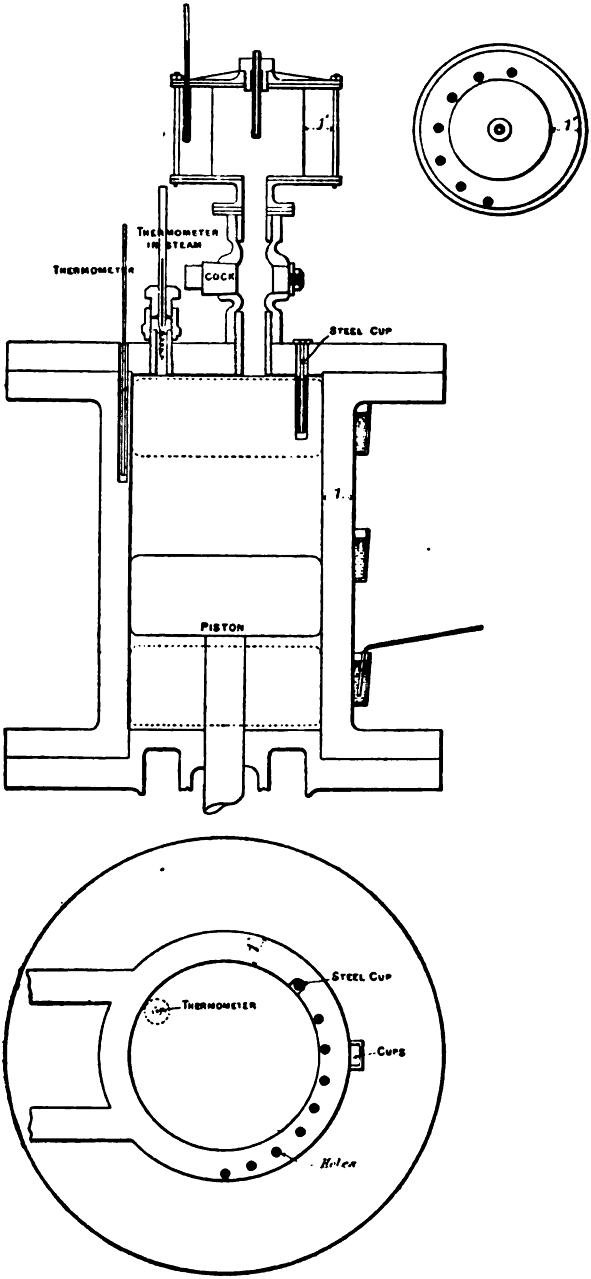
By BRYAN DONKIN, Jun., M. Inst. C.E.

THE authors of many modern treatises on the steam-engine deal with the question of the temperature of the cylinder walls, and arrive at results by calculations based on theories and assumptions of a somewhat doubtful nature.

The Author of the present communication has been impressed with the importance of getting some experimental data upon the subject, as there is perhaps no part of a motor which at ordinary speeds so greatly affects its economy as the cylinder walls. With that end in view, therefore, he has recently carried out some experiments, and trusts that the results will prove of value to engineers. His method of procedure was as follows:—A series of small vertical holes of about $\frac{1}{8}$ inch in diameter and 2 or 3 inches deep were drilled into the walls of a vertical cylinder at different distances from the bore, and spaced about 1 inch apart, as shown in section and plan in *Figs. 1.*

During the experiments it was found that, in order to get trustworthy results, the holes in the cylinder walls must not be placed near steam- or exhaust-passages, nor, indeed, near the steam-chest, but only in the normal parts of the walls. Into the holes, in which a little mercury had been previously placed, a small glass thermometer, duly tested, was inserted, in order to take the temperatures of the surrounding metal. The readings of the thermometer enable the mean temperature of the metal to be obtained, also a curve representing the thermal gradient through the cylinder walls. The form of this curve depends upon whether the cylinder is jacketed or not, protected or unprotected from the outer air. A comparison of the results thus obtained with the mean temperature of the steam and exhaust strokes is interesting. The latter temperatures can be easily ascertained from the pressures recorded on the indicator diagram taken at the same time.

Figs. 1.

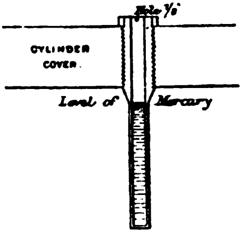

1'
1'
Thermometer in steam
Thermometer
Cock
Steel Cup
1
Piston
1
Steel Cup
Thermometer
Cups
Holes

From a limited number of experiments, the Author finds that the mean temperature of the walls at the top of a non-jacketed steam-engine is somewhat higher than the mean temperature of the steam taken from the top diagram during the double stroke. The exceedingly rapid alternations in the temperature of the steam during each stroke affect the temperature of the surfaces of the cylinder-walls in a similar manner. The depth to which this fluctuation penetrates varies naturally with the speed of the engine, or with the time to which the metal is exposed to the ever-changing temperatures of the steam. With a non-jacketed cylinder, and at low speeds, the Author finds this depth to vary from about $\frac{1}{10}$ to $\frac{1}{8}$ inch; but he considers that further experiments are needed to determine this point more exactly.

The thermometer placed in the hole nearest to the bore often rises and falls a few degrees. This is the more marked the lower the speed.

In the holes for the thermometers referred to above, the one situated nearest to the bore of the cylinder left about $\frac{1}{16}$ inch of metal between the mercury and the steam; it was impracticable to drill a hole nearer to the edge of the wall, and yet very desirable to get a thermometer still closer to the steam. In order to accomplish this a small steel cup was used—3 inches long and $\frac{1}{8}$ inch in diameter, the sides being about $\frac{1}{100}$ inch thick. After partially filling with mercury, this cup was inserted in the top cylinder cover (*Figs. 1* and *2*), and arranged so as to clear the piston. By means of a small thermometer placed with its bulb in the mercury, temperature readings could be taken during each stroke under various conditions of speed and steam-pressure.

Fig. 2.



STEEL CUP IN CYLINDER COVER.

It was seen that the mercury of the thermometer rose and fell regularly, keeping time with every stroke of the engine even at high speeds. The results were afterwards compared with the temperatures deduced from the indicator diagrams.

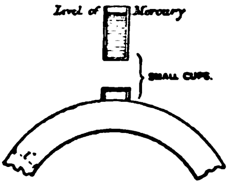
The results of the previous experiments with the very thin walls induced the Author to go a step further, and insert a thermometer directly in the steam without any intervening metal (*Figs. 1*). To a still greater extent, the thermometer rose and fell with the varying pressures and temperatures of the steam, when running slowly; the maximum reading of the thermometer almost coincided with the temperature of the steam at the initial pressure, and afterwards fell to practically the same temperature as the exhaust steam, the range in some cases being as much as 20° during the double stroke; the variation, however, was greatly reduced when the speed was increased.

At first it was feared that these latter results might be vitiated by the compression of the thermometer-bulb, the effect of which would have been to increase the apparent range of the temperature. On subjecting it, however, to a corresponding pressure at a constant temperature no appreciable error could be detected.

In the experiments described above, the temperature of the walls was only taken at the top of the cylinder along one horizontal section, or band, about 1½ inch deep. To continue the investigation, the Author considered it desirable to make similar experiments on the middle and bottom of the cylinder, to determine whether, in a double-acting expansive engine, the middle of the cylinder was cooler than the ends, or in a single-acting engine, whether the admission end was hotter than the exhaust end.

The method of determining the temperatures of the outside parts of the cylinder was as follows:—Small cast-iron cups, about 1½ inch long and 1 inch wide, were attached to the walls, as shown in *Figs. 1* and *3*, and, after filling them with mercury, a bent thermometer was inserted. In a double-acting engine, it was found that the temperatures at each end of the cylinder were practically the same, but were higher than the temperature in the middle; but when working single-acting, as great a difference as 27° has been recorded between the admission and exhaust ends of the cylinder; the variation of course depends upon the range of steam-pressure within.

Fig. 3.



In order to reproduce and study on a small scale the internal temperatures, a miniature metal apparatus, about 4 inches in diameter and 3 inches long, was attached to a cock on the top of the cylinder cover, as shown in *Figs. 1*. Holes were drilled in the walls of this apparatus in precisely the same manner and position as in the main cylinder walls before described, the thickness and external covering in both cases being identical, and the interior exposed to the same steam as the main cylinder. Observations on the temperatures of both the apparatus and the cylinder were taken at the same time, and were found to agree very closely. In another instance a double apparatus, similar to the small one described above, was tried. One of its cast-iron walls was

½ inch thick and the other 1 inch thick, the object being to compare the results with walls of different thicknesses, both of them being subjected to the same steam as the main cylinder. The apparatus has been also made with a steam-jacket, and a small piston inside was moved up and down to imitate as nearly as possible actual working conditions, and to keep the inside of the little cylinder clean. A mercury cup was used as in the other experiments, and a bare thermometer to take the temperature of the steam.

The internal surfaces of a steam-engine cylinder may be divided (following Mr. Kirsch's method) into three classes, as follows:—

First, the surfaces which are in contact with the steam and exhaust when the piston is at each end of the cylinder, or when the engine is on its dead-points; such surfaces are, the cylinder covers, piston, parts of cylinder walls, piston-rod and passages, and may be termed "clearance surfaces." They are usually dull and covered with a thin layer of grease.

Secondly, surfaces not exposed when the piston is at the end of its stroke, and which never come in contact with the steam and exhaust from the opposite side of the piston, *i.e.*, the ring of metal covered by the piston when the engine is on its dead-centres. Such surfaces are constantly clean and bright.

Thirdly, surfaces affected by the combined action of the two steam- and two exhaust-strokes on each side of the piston; in other words, those surfaces swept over by the piston during each stroke. They form the chief part of the cylinder barrel exclusive of the ends, and are always kept bright by the piston. The three types of surfaces are shown in *Fig. 4.* Suppose an engine fitted with a very deep piston equal in length to the stroke; then the surfaces of the walls affected by the steam during the down-stroke will be entirely different from those affected during the up-stroke, *Fig. 5.*

The above classification refers only to the internal surfaces of the cylinder walls; but the effect of the thickness of the walls, &c., must also be considered; such thickness may be divided into two distinct portions, each acting differently.

First, the inner portion in direct contact with the steam, which is generally alternately heated and cooled during each revolution. The metal to a well-defined depth absorbs and rejects heat during each steam- and exhaust-stroke respectively. Such portions of the walls only are affected by the variation in the steam temperatures corresponding to the varying pressures. This inner portion of the walls may be termed the "fluctuating or periodic thickness."

Secondly, the outer portion, or the rest of the metal outside the

Fig. 4.

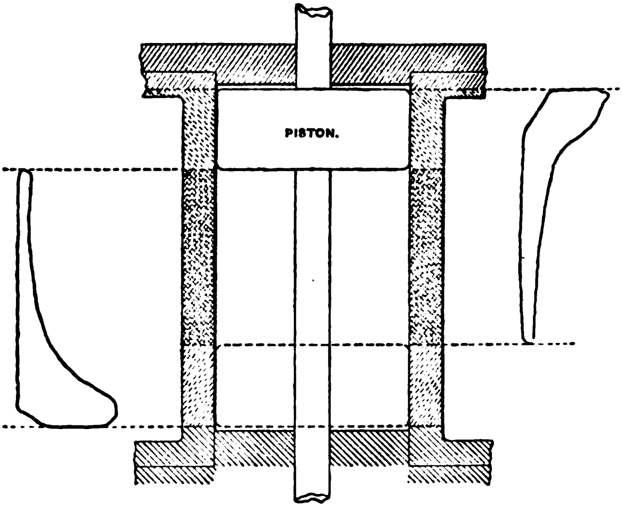
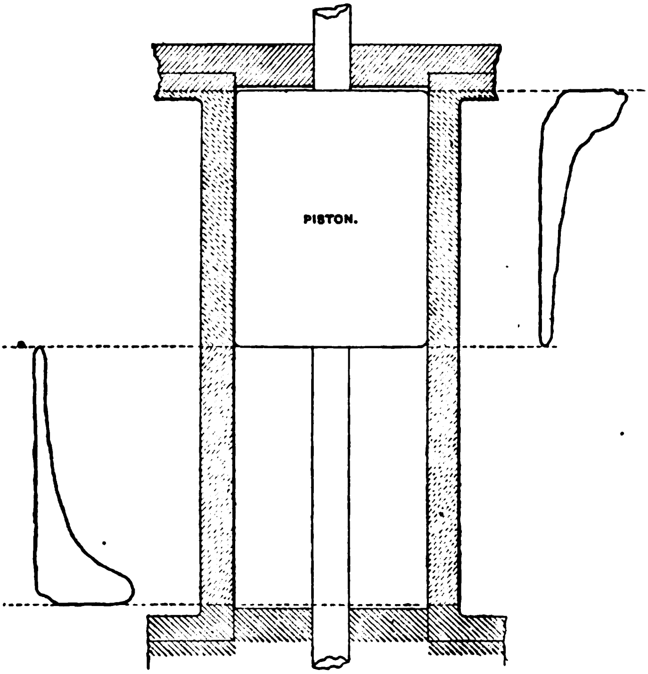


Fig. 5.



periodic thickness, which is by far the greater portion. This portion appears to be unaffected by the varying internal temperatures of the steam; the heat passes through it in one direction only, from the inside to the outside, and thence away by radiation; the rate at which it passes depends upon the clothing of the cylinder, the range of temperature between the internal steam and the external air, when no jacket is used. The heat that escapes in this manner must have passed through the periodic thickness of the walls, in which the direction is continually changing.

It may be added that the thermal gradient through the outer portion of the walls is generally nearly horizontal in vertical cylinders, which are well covered to prevent radiation.

It is interesting to know the position of the line where the periodic thickness ends and the non-periodic begins. It seems to vary much with the conditions of working, such as the speed, nature and condition of the surfaces considered. These complicated effects also depend doubtless upon whether the surfaces are bright and cleaned by the piston, or are left dull and not turned. On the latter oil or grease adheres more easily, as they are not scraped by the piston, and only the flow of steam and water cleanses them. The amount of water on the surfaces also probably affects their capacity for rapidly absorbing and rejecting heat. The time question, or number of seconds occupied by each stroke, is also an important factor.

Judging from the experiments made in the manner described above, with cylinder walls 1 inch thick, the periodic portion was approximately $\frac{1}{10}$ inch, and the non-periodic portion $\frac{9}{10}$ inch thick.

The Paper is accompanied by the diagrams from which the *Figs.* in the text have been engraved.

(*Students' Paper No. 266.*)

"Telephonic Switching."[1]

By CHARLES HENRY WORDINGHAM, A.K.C., Stud. Inst. C.E.

THE telephone, in annihilating the effect of distance, is akin to the electric telegraph; but it is superior, for instead of a written and generally abbreviated message, the sender is, as it were, present, and the answer being received immediately, a great saving in time is effected.

The telephone has become a necessity of commercial life, and it is this quickness of reply, together with the absence of any necessity for skill or training in the use of the instrument, that has effected this. A few figures showing the rate at which the use of the telephone has increased in London since 1882 may be of interest. The Author has selected approximately the same day in each year; and the following Table shows the number of subscribers, of calls on the day selected, the average number of calls per subscriber, and the number of exchanges in use to deal

Date.	Subscribers' Exchange Wires.	Calls on day named.	Average Number of Calls per Subscriber.	Exchanges.	Private Wires.
March 1st, 1882 . .	1,505	10,651	7·1	14	315
„ 1883 . .	2,400	20,471	8·5	15	537
Feb. 29th, 1884 . .	3,025	21,357	7·6	17	604
March 2nd, 1885 . .	3,447	22,969	6·7	18	836
March 1st, 1886 . .	3,875	25,597	6·6	18	933
„ 1887 . .	4,181	11,983[2]	2·9	18	981
„ 1888 . .	4,340	34,386	7·9	22	1,101
„ 1889 . .	4,635	37,680	8·1	21	1,526

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[1] This communication was read and discussed at a meeting of the Students on the 7th of March, 1890, and was awarded a Miller Prize in the session 1889-90.

[2] Many wires were broken down by the great snow-storm in December, 1886, and had not all been replaced by that date: hence the small number of calls.

with the calls. The number of private wires is added, though, of course, no record is kept of the calls on them.

The greatest number of calls in any one day was 51,714, on the 17th of December, 1888.

It would seem that the proper field for the telegraph is the transmission of news; nothing apparently can excel the celerity of the automatic transmitters now in use; but for transacting business, and indeed for all messages, the telephone must in time displace its rival.

The essentials of a good system of telephony comprise:—

(i) Clearness of the speech transmitted, which depends on the transmitter, and the line and the receiver being of good design; if any one of these be faulty, the conversation will be unsatisfactory.

(ii) Rapidity of connection between the subscribers to the system. Nothing is more tantalizing than to be kept waiting when wishing to deliver a message; this is dependent on the system of switching adopted.

(iii) Freedom from interruption, whether by extraneous noises or by accidental disconnection; this is secured by proper construction of the line and an efficient switch.

In this Paper, the Author purposes confining his remarks to the various methods of switching at present in use.

Every instrument consists of two parts, the transmitter and the receiver. The current from a battery, usually one Leclanché cell, is led through the microphonic contact which, in the case of the transmitter most widely used, the Blake, consists of a platinum spring pressing against a button of carbon, and through one coil of a transformer. This forms the "primary" or "local" circuit. The receiver and the secondary coil of the transformer are connected in series, and the circuit is completed through the distant instrument by two lines, if a metallic return be employed, or more usually by one line and the earth. At the distant station precisely the same arrangement is made. Plate 12, Fig. 1, shows the instruments thus joined up. Means are provided for breaking the battery circuit when the transmitter is not in use, the most convenient way being by a lever on which the receiver is hung; when this is removed a spring causes the lever to complete the circuit.

It is necessary for the operator at the exchange to be able to call the attention of the subscriber, and this is always done by a bell, actuated either by a continuous current from a battery or by an alternating one from a magneto machine. The subscriber employs the same means to signal to the operator; but instead of the current ringing a bell, it actuates an indicator.

In nearly all urban systems an earth return is used at present, a metallic return being employed only for long lines; in what follows the descriptions must be understood to apply to lines with an earth return, unless the contrary is stated.

Each subscriber, then, has a single line of his own in connection with some central point called the "exchange"; and the problem to be solved is to connect any one of these lines with any other of the whole system. To do this, the various subscribers are grouped together, according to their districts, into local exchanges, and these exchanges are connected by trunk wires. What might perhaps be called the duty of the trunks is far greater than that of the subscribers' wires, since the latter are idle except when carrying the messages of their respective owners, while the trunks are used indifferently for any subscriber, and are therefore at work all day long.

The trunk system in London is almost perfect, and a complete breakdown of communication between any two exchanges is nearly impossible. All are connected with a central exchange, used exclusively for trunks; and in addition to this, each exchange, with one or two exceptions, has lines to a considerable number of other exchanges, so that there is always a choice of routes. Thus, referring to Plate 12, Fig. 2, if Westminster exchange wishes to speak to Heddon Street, the two exchanges can speak direct, or through the Central exchange; or, supposing all the lines to Heddon Street and the Central be broken down, they could still communicate through some other exchange, say Kensington.

Each exchange, as a rule, has one of its trunks to the Central exchange reserved for the exigencies of the service. This is always No. 1, and is known as the "speaking-line," the rest of the odd lines are "down" lines, or lines under the control of the Central exchange, and to which the operator there connects other exchanges wishing for the one under consideration. The even are the "up" lines, and are controlled by the exchange to which they belong.

At the Central exchange an operator is always listening on the speaking-line of each exchange, and when that exchange wants a connection made, the operator calls on the speaking-line asking for the required exchange to be connected on a specified up-line; the Central operator connects this with a down-line to the required exchange, and the first exchange rings and asks for the number wanted.

An example will make this clear. Suppose Westminster wants

Smithfield; the Westminster operator, to use the language of the switch-room, "goes on" the Central speaking-line and calls "Central—Smithfield 2" or whatever up-line is to be used. The Central operator repeats the order and connects 2 Westminster with any disengaged down-line to Smithfield. Westminster rings on the line and asks Smithfield for the number wanted; Smithfield rings this subscriber up, and connects him to the trunk, at the same time telling him he is "through." Westminster connects his subscriber, and the operation is complete.

When one local exchange communicates direct with another, a speaking-line may be used, in which case either exchange rings on the speaking-line, and asks the other for the required number on a specified line; or else, no speaking-line is used, and the exchanges simply ring on the lines on which they want the numbers.

Each exchange has a certain group of numbers assigned to it, so that as soon as the first two figures of a number are known, the exchange at which it will be found is apparent.

Having considered briefly the general principle on which a subscriber on one exchange is put in communication with one on another, the means whereby the required connections can be made must be examined. In London all the telephone lines are overhead, and the wires and cables are brought on to a structure known as a "derrick." In the case of small exchanges this is a number of wrought-iron poles braced together; but when a large number of wires and cables has to be dealt with, massive wrought-iron frames are used. The lines on the roof are connected by means of twenty wire cables with the test-room, each cable having a slat of wood with twenty terminals apportioned to it. The order of the lines on these terminals is determined by the district from which they come, not by the numbers of the subscribers to whom they belong. Running along one side of the test-room is a vertical teak board, studded with carefully insulated terminals about 2 inches apart; they go right through the board, and the wires to the exchange are attached to them on the other side. These terminals are arranged in vertical rows of twenty each, and are numbered consecutively with the numbers of the subscribers on the exchange. Cross-connecting wires join them with the terminals to which the outside cables come, so that on the "terminal-board," as it is called, the subscribers are arranged in their numerical order, irrespective of the locality in which they dwell.

By this arrangement very little disturbance is occasioned by changes among the subscribers; if one subscriber leaves the exchange, his cross-connecting wire is withdrawn, and, although another subscriber, having a different number, is afterwards brought in on the same wire in the cable, a new cross-connecting wire joins his line to its proper terminal on the board without in any way disturbing the other wires.

Having now got the subscribers arranged in order, the methods for rapidly connecting any one of them to any other, and the means provided for speaking to each from the exchange will be described.

The simplest way in which this is done is by a modification of the Bell system. Each line passes through an indicator, and thence to a spring known as a "slipper" resting on a plate or "shoe" connected to earth. The indicator consists of an electromagnet, having an armature prolonged into a lever terminating in a hook; this when at rest prevents a shutter from falling, and when the armature is attracted by the subscriber ringing and sending a current through the magnet coils, the shutter drops, disclosing the number of the line. The indicators are either mounted in tiers on a board with their respective slippers beneath them, or in groups by themselves, and placed on either side of a board containing their slippers. All the lines in the exchange are treated in this way, the first hundred being brought on to the first or A board, the next on to the B board, and so on; the trunks have a board to themselves in an exchange with any pretensions to size.

The lines are connected to the indicators and the indicators to the slippers by cables, usually containing twenty-one wires, twenty wires being used and one reserved as a spare wire; this last is put to earth with the object of lessening the induction between the other wires. The wires are of copper, No. 20 B.W.G., are double-cotton covered and thoroughly paraffined, the cable being cased with braided cotton. Each wire has a distinct colour or combination of colours, so that no confusion can arise as to identity. An extremely neat method is in use for allowing spare material on the wires without taking up precious space. Suppose the wires of a cable have to be connected to a row of twenty terminals; the covering is stripped for a certain length and the spare wire drawn out; the first wire is then curled round the other nineteen wires for a distance equal to that between two consecutive terminals; the next wire is curled round the remaining eighteen wires, the next round seventeen, and so on to the last which is formed into a spiral. In this way a tapering cable is formed, the largest diameter of which is only slightly greater than that of the original cable; the ends of the wires are brought out in their proper order, and each has plenty of spare material in it for use in case of breakage.

The cables are carried in wooden troughing with a hinged lid, thus permitting easy access to them, and avoiding the danger to insulation entailed by clips and other fastenings. The single wires used for other connections are also run through this troughing.

To connect two subscribers on the same board, flexible cords terminating in plugs, like that shown by Fig. 3, are used. When these plugs are inserted between the slippers and the shoes, the brass plates make contact with the respective slippers, which are insulated from their shoes by pieces of ebonite.

The several boards in the exchange are connected by wires terminating at each end in flexible cords with plugs; these cords pass through holes in the table on which the board stands, and are weighted so as to run back when not in use. To connect subscribers on different boards these cross-connecting lines are employed instead of the simple cords just described. It will be noticed that each board is like a little exchange, and that the cross-connections are like trunks.

The operator's instrument has one line put to earth, and the other connected to a flexible cord terminating in a plug similar to those described above, but with the brass plate prolonged as shown by Plate 12, Fig. 4. By inserting this thin part between the slipper and the plug of either of two subscribers who are talking, the operator can speak to both without disconnecting them, his instrument being connected as a shunt to earth. This operation is known as "tapping."

When a metallic return is employed, the shoes, instead of being put to earth, are connected to the return wires of their respective slippers. A double instrument plug must be used, consisting of two flat plates separated by a piece of ebonite, the two leads of the operator's instrument being connected to them respectively. Similar double plugs are required for connecting the subscribers.

The system just described is not applicable to very large exchanges; one better adapted to the purpose is the Edison peg-board. In this the exchange is built up of boards, placed vertically, formed of two series of brass strips, $\frac{1}{4}$-inch wide, crossing one another at right-angles, each strip being insulated from the others. Plate 12, Fig. 5, is a part section, and Fig. 6 a part plan, of the board. Conical holes are drilled at the points of intersection, so that by inserting a peg at any point, the two strips there crossing are connected together. The subscribers' lines are connected through indicators to the vertical strips, and the horizontal ones take the place of the flexible cords in the Bell system. Each subscriber's line has a peg, which puts it to earth when he is not talking, and is used to connect his strip to any horizontal strip when required. The operator's instrument, instead of terminating in a flexible cord, is connected to a horizontal strip; and a spare vertical strip and two pegs enable the operator to speak on any horizontal strip. The trunks are, of course, treated in the same manner as the other lines, the only exception being in the case of the speaking-lines, each of which, in a large exchange, is brought to the lever of a Morse key, whose hinder contact is connected to the indicator of the line; the front contacts of the keys are connected together and to the operator's instrument, so that .he can communicate on any speaking-line by merely depressing the key corresponding to it.

This system, though it was much in use in London at one time, is being rapidly superseded by the boards presently to be described. When the number of subscribers reaches four hundred or five hundred, the Babel caused by the operators calling to one another is indescribable; and, moreover, during busy parts of the day, the number of cross-connections required becomes impracticably large and delay results. Compared with the most modern boards, the methods of the Bell and Edison systems are clumsy, the co-operation of several persons to make one connection causing much loss of time. The system that is ousting all other forms is the Multiple. In this each operator, while only having to attend to a limited number of lines, has control over the whole number in the exchange. Two subscribers are connected by one person at one operation, whatever may be their position in the exchange. This simplicity of working is brought about by a great increase in the complexity and labour of fitting; but the results amply compensate for the extra trouble and expense.

PRINCIPLE OF THE MULTIPLE BOARD.

Each line passes through a series of contacts known as "spring-jacks," or more shortly "jacks," one being placed on each board in the exchange; from the last jack it passes to the indicator, and thence to earth. Plate 12, Fig. 7, represents this diagrammatically. Each jack consists of a spring resting on a stud; the line comes on to the first spring S_1, the first stud P_1 is connected to the second spring S_2, the second stud P_2 to S_3, and P_3 to S_4, while P_4 is connected to the indicator, and so to earth. A certain number of indicators is assigned to each board, and, on whichever board the indicator is, there is placed the first jack, which is known as the "home section." The second jack is on the first board, the third on the second, and so on; so that each board has two jacks for each of the lines whose indicators it contains; this is not necessary, but it adds greatly to the convenience and symmetry of the board. It is evident that if any one of the springs, say S_2, be depressed, connection is made with the line through the first jack, while the jacks beyond S_2, together with the indicator, are cut off from the line. Referring now to the lower part of Fig. 7. A is a plunger, which is always in contact with one terminal of the "ring-off" indicator B; the other terminal of this indicator being connected to the upper contact of the key C. The springs D and E are connected respectively to the upper contacts of the keys C and F, and the studs G and H to the two lines of the operator's instrument, in the secondary circuit of which is placed a cell whose office will be explained further on. The lower contacts of the keys C and F are connected to some source of electro-motive force, for ringing, either battery or dynamo. The levers of these keys are connected respectively to the plugs K and L, which in their normal position rest on the plates M, N, joined to earth. When these plugs are inserted in the jacks, they make contact with the springs, at the same time separating them from their studs. Suppose, now, the plunger is up in the position shown in Fig. 7, there then is a circuit from K to L, through the upper contact of C, the spring D, the stud G, the transmitter circuit, the stud H, the spring E, and the upper contact of F. Let, now, the plunger be depressed, then there is a circuit from K to L through the upper contact of C, the ring-off indicator, the plunger, the spring E, and the upper contact of F. Suppose a subscriber to ring, the current flows through all the jacks and the indicator to earth, the indicator drops, the operator raises the plunger, and, lifting the plug K off its earth-plate, inserts it in the home-section, thus cutting off all the other boards, and completing the circuit through his own instrument, L resting on its earth-plate furnishing the earth connection. He depresses C, thus ringing the subscriber's bell, and inquires what number is wanted; he then takes the other plug L, and inserts it in the jack on his own board belonging to the number asked for; the result of this is to cut the subscriber off from his indicator and the boards beyond the one in question, and to connect him to the first subscriber through the operator's instrument; F serves to notify the second subscriber. As soon as the operator hears that conversation has begun he depresses the plunger, cutting his own instrument out of the circuit, and inserting the ring-off indicator; when this drops owing to either of the subscribers ringing off, the plugs are replaced in their former positions.

It is evident that some means must be adopted to show whether a plug is already in a jack on some other board, for if another operator inserts a plug at P_2 S_2, when one is in P_3 S_3 he will interrupt the conversation, and if at P_4 S_4 his plug will be connected to nothing. The following is the device adopted:—In front of each jack is a metal cylinder called the "test," and all these tests T_1 T_2 T_3 T_4, are connected together, but insulated from everything else. If, now, a plug is inserted at any jack, it has to pass through the test and make contact with it, thus putting all the tests to earth. It has already been mentioned that there is a cell in the secondary circuit of each operator's instrument. If, therefore, any operator takes his plug, and taps it on the test, he will get a click in his receiver, if the tests are to earth, and the line engaged; but if the line is clear the tests are insulated, and he gets no click.

Passing on to the way in which the principle just described is carried out in practice, the board consists of an upright framing of American walnut, resembling somewhat in general appearance an old-fashioned piano. The upper part of the board is divided into panels, and in these are fixed the jacks: below is a shelf through which pass the cords for the plugs resting on it: beneath this shelf are the indicators, and lower yet is another shelf on which are placed the "triggers," or "cam-levers," actuating the plungers, together with the ringing keys. The smallest size contains indicators for one hundred subscribers and twenty trunks, also thirty ring-off indicators. It has provision for three operators' instruments, ten triggers being assigned to each. There is space for fifteen hundred jacks; the maximum possible number of boards of this pattern, therefore, in any one exchange, is fifteen. These small boards are in use in many of the London exchanges; but a large size has been erected at the East India Avenue. Here each board has two hundred subscribers' indicators, and forty-eight ring-off indicators, requiring four instruments, each with twelve triggers. Every board has space for four thousand jacks. The details of the boards vary, however, in almost every exchange.

SPRING-JACKS AND TESTS.

These are mounted in sets of twenty in blocks of ebonite 12 inches long. Plate 12, Fig. 8, represents a section through a jack and test. A is the test, B the line-spring, C the stud. Each terminates in a small tab for convenience of connection. In the larger boards the home-section jacks are in sets of twenty-five each.

TRIGGERS AND KEYS.

The usual form of trigger is shown in section by Fig. 9. A is the trigger proper, B the plunger which it actuates, C and D are two strips of brass connected to the operator's instrument, and common to ten triggers. A brass strip, connected to a source of electro-motive force for ringing, and common to twenty keys, is placed in front of the triggers. An improved form of trigger, used at the East India Avenue exchange, is shown by Fig. 10; it appears less likely to get out of order than the older form.

PLUGS.

The ordinary form of plug is shown by Plate 12, Fig. 11, and consists simply of a brass plug with an insulating handle; but an improved form, possessing great advantages, has lately been introduced into several of the London exchanges. The tip (Fig. 12) that makes contact with the line-spring is insulated from the rest of the plug, which is connected through one conductor of a twin cord direct to earth. In this manner the current from the testing cell does not go through the subscriber's line, and he is therefore unable to hear the click when his line is tested. This necessitates an alteration in the connections of the boards; the earth-plates on which the plugs rest, instead of being connected together and to earth, are connected to their respective plug-cords, and they are put to earth by the outside of the plug. A further advantage is that with this arrangement it is impossible to listen on the tests to the conversation.

INDICATORS.

These are of a form peculiar to the multiple boards; they are made in sets of ten, and are very compact. A strip of wrought-iron forms a common yoke, and to this are screwed the limbs of the magnets; on these are slipped the magnetizing coils, and the armature is supported by a brass frame slipped on the ends of the limbs, and held in place by set-screws. The shutter is attached to the front of the yoke, and in falling depresses a spring, causing it to make contact with a point, insulated from the yoke, and so complete the circuit of a battery actuating a bell, which thus rings when any indicator falls. This bell is only used at night when the calls are few and far between.

There remains to describe the method pursued in connecting up the boards, which, as may have been gathered from what has gone before, is a matter of considerable labour and complexity. Cables similar to those previously described, but of No. 22 B.W.G. tinned copper wire, insulated with india-rubber and paraffined cotton, are employed. Each section of jacks requires four of these cables:—(i.) one for the incoming lines, its wires being soldered to the line-spring tabs, its other end being attached to the studs of the previous board; (ii.) one for the outgoing lines, soldered to the stud tabs, its other end forming the incoming lines of the next board; (iii.) one for the incoming and (iv.) one for the outgoing tests, the wires of both being soldered to the test tabs, the other ends of these cables going to the tests on the boards on either side. The wires are identified by their colours as before. The old method of running the cables was in troughing at the back of the board, out of which they were brought in their proper places, and passed through perforations in vertical wooden boards; this had the great disadvantage of rendering the removal of a section impossible without unsoldering the wires. The difficulty is overcome in the new method by supporting the cables on racks, formed of steel pins screwed into a cast-iron base attached to the board. A great improvement has lately been introduced by running the cables straight along on the pins without dipping down into the troughing, which is thus unnecessary. This renders the board more accessible and saves a large amount of cable. More important than the saving in first cost is the diminution of induction between the wires, owing to their decreased length.

A still further improvement is effected by making the racks of thin wrought-iron bars, twisted at the end, and hinged to the board.

METHODS OF RINGING.

In connection with the multiple boards, the employment of alternating currents from a magneto machine is nearly universally adopted, and instead of each operator having a hand magneto, the ringing-bars are excited by a little dynamo with permanent magnets, driven by some kind of motor. Every precaution is taken to avoid a break-down, two dynamos being provided, exciting the ringing-bars of alternate instruments, and in addition a "pole-changer," an instrument which sends reversed currents from a battery to the line, and works the bells, though not so well as a magneto. Plate 12, Fig. 13, is a diagram of this instrument; N_1 N_2 are two soft iron pole-pieces, similarly magnetized by a permanent magnet, NS, and between them hangs a soft iron armature A, pivoted at O, and prolonged into a lever L, having a bob, B, to adjust its time of vibration. On each pole-piece is a coil, and these coils are so wound that when a current flows through them, one pole is strengthened and the other weakened. One end of the coils is put to earth, and the other is connected to the lever. Two springs S_1 and S_2, connected respectively to the two poles of the battery, press against a pillar, P, connected to the ringing-bars, and just clear the lever when it is in the middle position, which is, however, one of unstable equilibrium, so that in practice it is always to one side or the other. Suppose it is to the left, then it makes contact with S_1, and there is a circuit from the battery through S_1, the lever, the coils, earth, the subscriber's instrument and line, the ringing-bars, the pillar P_1 S_2, and so back to the battery. The effect of this current is to weaken N_1 and strengthen N_2, thus pulling the lever over and reversing the pole that is to line. A similar effect occurs on this side, and the lever is kept continuously vibrating. Formerly a separate cell was used to work the lever; but the method described avoids the necessity of the instrument working except when actually in use. The instrument is extremely objectionable, as these abrupt make-and-breaks cause an intolerable noise on neighbouring lines, inducing currents which rise suddenly to a maximum, such currents, as is well known, affecting the telephone much more than pulsating ones of the same range and total quantity from a magneto machine. A somewhat interesting point, noticed by the Author, is that the instrument is, to a great extent, governed by the bell it is ringing vibrating strongly when the period of vibration coincides with its own, and but feebly in the other case. It will be remembered, of course, that with a magneto bell the circuit is never broken, so that it is the electro-motive force set up by the moving armature of the bell that causes the action.

At the East India Avenue exchange the out-going trunks appear on every board in the usual way, but a special board is provided for the incoming trunks. This board is similar to the others as regards the jacks; but instead of the incoming lines being brought to the jacks, they pass through indicators and then terminate in flexible cords and plugs, each line having a trigger to enable the operator to speak on it. Since each line has a plug, no pairs are necessary as in the other boards, and the lines' own indicators serve as ring-off indicators. When an indicator falls, the operator has simply to depress the corresponding trigger in order to reply, and then to insert the plug in the required jack, thus saving one operation. This principle has been carried still further in the latest development of the multiple board, and every line, after passing through the jacks in the usual way, terminates in a cord and plug. This is known as the Single Cord Multiple.

A short description of the system in use at the Central Trunk exchange may not be out of place, as it possesses several special features. The odd lines, which are the down-lines under the control of the Central exchange, are brought to multiple boards, of which there are six, in the usual way. The jacks are of an older form than those previously described, being larger, and each being fastened separately to a block of ebonite. A section is shown in Fig. 14. Instead of the test-cell a "buzzer" —a very noisy contact-breaker—is employed for ascertaining whether a line is engaged. On the top of the line-spring is fixed an ebonite stud, A, on which rests a flat spring, B, insulated from the line-spring and connected to one pole of the buzzer battery, the other pole of which is joined to a buzzer; the other terminal of this buzzer is connected to a wire which runs round all the boards. Each instrument has a "buzzer plug" at the end of a flexible cord connected through a receiver to this wire, Fig. 15. The flat spring, B, Fig. 14, when a plug is inserted in a jack, is raised into contact with a stud, C, to which is connected a screw, D, in front of the board. If, now, the line be engaged, B will make contact with C, and if the screw D be touched with the buzzer plug the circuit will be completed through the receiver, and the buzzer will work, the former emitting a loud rattling sound. For any given line, the springs B and the screws D are respectively connected together on all the boards.

Three instruments are provided for every board; and each has one lead to earth, and the other to a bar running beneath a set of keys, each of which is labelled with the name of a speaking-line to an exchange. Similar keys on every instrument are connected together and to a plug, which plug is inserted in a jack corresponding to the particular speaking-line. By depressing the proper key any speaking-line is connected to any instrument in the exchange. One busy exchange or several small exchanges are assigned to each operator, and the key on his instrument corresponding to that exchange is kept permanently depressed, thus enabling not only that exchange but also any other operator in the Central exchange, if he depresses the proper key, to speak to him. Fig. 16 shows the arrangement.

The even lines of each exchange terminate in flexible cords and plugs on that board at which the operator sits who attends to the particular exchange.

It may be well to describe how a connection is made. Suppose Westminster requires a number on the Eastern exchange: Westminster calls to the Central on the speaking-line, "Eastern six Westminster"; the Central operator picks up the plug that six Westminster terminates in, and, buzzer plug in hand, tries or "buzzes" the Eastern jacks; as soon as he finds one that does not buzz he inserts the Westminster plug and the operation is complete.

All long trunk lines are run with a metallic return circuit, and in order to render them available for the use of subscribers whose lines have an earth return, it is necessary to use "translators" or converters, in which one coil is connected to the earth circuit and the other to the metallic "loop." In the earlier form they were simply made like ordinary induction coils with a bundle of straight soft iron wires for core, the magnetic circuit being therefore open.

An improved form, now superseding them, is made on the principle of modern electric-light converters, the magnetic circuit being complete. The core is built up of E-shaped pieces stamped out of thin sheet-iron, carefully insulated from one another by paraffined paper; the coils are oval and embrace the middle part of the E; the plates, being threaded in from opposite sides, completely enclose the coils. This form has several distinct advantages over the older:—

(1) It must be more efficient.

(2) It can be put close to another without one interfering with the other; and

(3) It is easy to ring the local circuit from the loop or *vice versâ*, a thing impossible with the old form.

In spite of their necessarily greater efficiency, these translators do not seem practically to give better results in speaking; on the contrary, they seem to have a tendency to muffle the sound somewhat. This is rather hard to account for, and the Author would suggest that possibly the absence of the demagnetizing force of the ends of the core, which must be considerable in one so short, has something to do with the result.

It is usual to wind a third coil on the translator to enable an operator to tap into the circuit, its introduction making no perceptible difference to the conversation.

A good illustration of the effect of a closed secondary circuit, in diminishing the self-induction of the primary, is afforded by these instruments. When the local circuit is closed and a magneto is worked in the loop, it actuates an indicator in the loop without difficulty; but if the local circuit be open the indicator fails to respond.

The long-distance trunk board in the Central exchange is arranged thus:—

On a vertical board there are three tiers of springs—the "main," the "local," and the "tertiary." Each line has a pair in each tier, the springs rest on studs, and are thus connected:—The top pair of springs is connected to the two lines forming the loop through an indicator, one coil of which is on one line and the other on the other, so as to balance the two lines as regards induction. The underlying studs are the ends of the primary coil of the translator. The next pair of springs is connected, one to earth, the other to a series of jacks on the ordinary boards in the exchange, and the corresponding studs to the secondary coil; while the third translator coil terminates in the third pair of springs. Ordinary triggers and cords are used for connecting, except that double cords are employed, the two leads from the operator's instrument being connected to them respectively. The plugs are of ebonite and have two flat brass strips side by side, forming the ends of the cords. The arrangement is shown in Fig. 17.

A most ingenious system, by which the use of indicators is dispensed with, is in use in America under the name of the "Law" System. Each subscriber is connected to the exchange by a single wire in the ordinary way; the subscribers are divided into groups of, say, fifty, and a wire starting from the exchange is run through all the group, terminating again in the exchange. An operator is always listening on this wire, and any subscriber wishing for a number has simply to loop his instrument into this wire and tell the exchange his number and what he wants. The operator merely connects the two lines, the first subscriber himself ringing up the number he requires. The switch for looping in the instrument is shown in Fig. 18. It will be seen that a defect in any one of the fifty switches would disable all the instruments on the circuit, this being a very formidable objection; but it is overcome by the "Mann" System, which, although apparently a modification of the "Law," is claimed by the inventor, Mr. J. J. Mann, to have been independently devised by him. Here a common wire is run round the whole group as before; but, instead of the instruments being looped in, each forms a shunt from the wire to earth. Plate 12, Fig. 19, shows the key for effecting this connection. This system is in use in Dundee with, the Author believes, very satisfactory results. Its advantages are great. It brings the subscriber into direct and immediate contact with the operator, without the comparatively clumsy signalling apparatus of an indicator, with its liability to stick and get out of order; and it also does away with the necessity for ring-off indicators and their injurious self-induction, as the subscriber can tell the operator when he has finished and, if desired, ask for another number. Much of the operator's time is saved by the subscribers ringing one another up, and there is no danger of their being cut off before they have finished their conversation. The operators are enabled to speak to one another by much the same means as are in use in the Central London exchange. Obviously this principle is applicable to any of the boards described.

The most important systems of switching have now been explained, and it may be well to see how they fulfil the conditions set forth at the beginning of this Paper.

(1) Rapidity of connection. The Multiple is far ahead of the others in this respect; the Single Cord making any connection at one operation.

(2) Freedom from interruption: (*a*) By extraneous noises. The Multiple is at a disadvantage here on account of the excessive length of cable required. (*b*) By liability to accidental disconnection. This is almost impossible with the Multiple, not easy with the Bell, and very possible with the Edison system. As regards expense, the Multiple is by far the most costly, though the extra outlay is amply repaid by the improved service and the smaller number of operators required.

The Multiple boards are undoubtedly the best in existence, but it cannot be denied that they have many faults; the enormous number of contacts, nearly all of which are "dead"—that is, not rubbing contacts—are a weak point, inasmuch as any one is sufficient to interrupt the continuity of the circuit. In a moderately large exchange there may easily be ten of these in the circuit of two subscribers. Another source of trouble are the flexible cords, which wear very rapidly. Again, the great length of cable necessary acts injuriously, by introducing much mutual induction between the lines. However, in spite of its faults, the Multiple is the only board that can deal satisfactorily with large numbers of subscribers. The nearest approach to an ideal exchange would be one in which a single-cord multiple board was fixed, the indicators replaced by the Mann system, and worked by operators who never talked to one another.

There are many excellent systems not described in the Paper, notably the Post Office, which is very suitable for small exchanges; but the Author believes that the board of the future will be the Multiple.

The Paper is accompanied by photographs, and a sheet of tracings, from which Plate 12 has been engraved.

OBITUARY.

Dom LUIZ, FILIPPE, MARIA, FERNANDO, PEDRO DE ALCANTARA, ANTONIO, MIGUEL, RAPHAEL, GABRIEL, GONZAGA, XAVIER, FRANCISCO DE ASSIS, JOÃO, JULIO, AUGUSTO, VOLFANDO, SAXE COBURG GOTHA DE BRAGANÇA E BOURBON, King of Portugal, was born October 31, 1838, in the royal palace of Necessidades, being the second son of Queen Marie II. and King Ferdinand.[1]

The first Duke of Oporto showed from his earliest years an irresistible desire for a sea-faring life. On this account, at eight years of age, he entered the navy as a marine on October 9, 1846. He was promoted to the rank of Lieutenant on May 19, 1851, and to that of Captain on October 29, 1854. In 1857 he was appointed commander of the brig "Pedro Nunes." Under the command of Dom Luiz, the ship carried out different commissions in the Tagus, going to Gibraltar on March 19, 1858. When he returned to the Tagus he was captain of a frigate, to which post he had been promoted on March 24. On June 12, 1858, he was appointed commander of the corvette "Bartholomeu Dias," which command he retained until his accession to the throne. As a seaman, the proofs of his dash, competence, and enthusiasm for the service were shown not only by the respect he inspired in all, from the lowest sailor to the highest officer, but also in the success, recorded in the English papers, which he achieved in a kind of regatta, which took place between some English vessels, which were acting as a convoy to his ship, the "Bartholomeu Dias," when the Empress of Austria returned from Madeira. Under the command of Dom Luiz, the "Bartholomeu Dias" became at that time a model ship. He surrendered the command on Nov. 9, 1861, and two days after, on the death of his brother, King Pedro V., ascended the throne of Portugal.

The reign of Dom Luiz I. was one of peace and tolerance, affecting the whole national life. After the short and sad reign

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[1] The substance of this memoir is from the *Diario Illustrado*, Lisbon, Oct. 26, 1889.

of Pedro V., King Luiz inherited the crown at a time when old enmities had been extinguished. Portugal turned to the task of restoring her impoverished resources; and the wisdom, good nature and optimistic views of the king joined him hand-in-hand with his people in their new life. He began by suppressing the irritating disputes, which had agitated the last years of the previous reign, and gave his ministers a free hand to bring about changes in the internal economy of the country. He reformed the law of entail in anticipation of its abolition; made estates in mortmain subject to common law; removed the bar of the Douro; did away with the tobacco impost; promulgated the civil code; reformed the law of ownership, and completed the task of abolishing entailed estates; reorganised the public service; centralised the control of roads; encouraged the formation of railways; bridged all the rivers: in a word, under his influence, Portugal assumed the appearance of a different country.

The Northern Railway, which for a long time had terminated at a short distance from Oporto without crossing the Douro, was finished and the bridge constructed which bears the name of Maria Pia, and is one of the finest pieces of engineering in the country. The Minho-Douro railways, and those in the Beira Alta and other lines, were made. The Portuguese colonial possessions became of more importance, and slavery was suppressed there. During his reign many eminent Portuguese travellers did good service in African exploration work; the Congo Free State was founded, and after long controversy the rights of Portugal and other powers in the neighbouring territories were settled.

Calm criticism will later on appreciate these profound changes, and will analyse their causes and effects. Without trespassing on the domain of history, it may be said that the reign of Dom Luiz will be known as a period of undoubted activity, and of the revival of the country, which seemed, amid the troubles of the second quarter of this century, to be doomed to decay.

As a constitutional sovereign Dom Luiz might be taken as a model; scrupulously observant both of the etiquette and the duties of his high position, he yet knew how to gauge changes of opinion with fine tact. In his later years he frequently remarked smiling, that he was the third in order of age among the crowned heads, and the significance of the fact was not lost upon him. A great journalist wrote at one time, rather in a burst of sincerity than in an impulse of flattery, that the King was the sole force in Portugal; but the king's power came not from inopportune energy of character, nor from any unconstitutional intervention in the duty of the government. It sprang from the profound knowledge of men and affairs in his country—a knowledge which gave him the right of arbitrating between parties and politicians. And his power was all the greater that it was exercised quietly, without ostentation or violence, always in that calm and serene manner in which a truly constitutional ruler should act. The King appeared always to bow before unforeseen circumstances; often, however, it was he who brought them about.

Dom Luiz devoted his leisure time to intellectual and artistic pleasures. His cultivated mind, familiar with most of the principal modern languages, was versed in classic and modern literature. He left, in his translations of Shakespeare, clear proof that his knowledge surpassed the limits of mere dilettanteism. His pleasant and varied talk always showed his deep knowledge and his enquiring spirit. Gifted with quick perceptive faculties he became easily master of subjects and questions of the most varied nature, and specially enjoyed obtaining detailed information on professional subjects which, as a rule, only interest the faculty themselves. A great lover of painting, he enriched the Ajuda Gallery with valuable pictures; and was himself a skilled painter in oils and water-colours. A missal presented by Her Majesty to the late chief lady-in-waiting, the Countess of Sousa Coutinho, adorned with illuminations by the King with pen and brush, was a real work of art. The late monarch also formed a collection of fine pieces of sculpture in the halls of the palace, the principal of which were the four beautiful statues in the entrance-hall, which were universally admired, and the fine "D. Sebastian," by Simon d'Almeida. His taste for music was well known and constantly cultivated, and at last, when his malady had confined him to a wheeled chair, his favourite pastime was to listen to the Hussla quartett.

In his travels to foreign Courts in Europe, the late Sovereign conquered all hearts by the affability of his manners and the lofty culture of his mind. The venerable Emperor William had a deep, almost fatherly affection for Dom Luiz, of which there remain numerous tokens in his letters. There are also many proofs of the close bonds which existed between the Queen of England and Dom Luiz, which tided over many a serious difficulty. He was an intimate friend of the Swedish King Oscar, the King of Italy, the Emperor of Brazil, and other sovereigns, to whom he was nearly related and from whom he always received delicate proofs of esteem. Indeed the recent literary convention with Brazil was owing, in a large degree, to the direct action of Dom Luiz and the Emperor working together.

He died prematurely on the 19th of October, 1889, when barely fifty-one years old, in a small bed-room of the citadel of Cascaes near the sea he so loved, surrounded by the sorrowing Queen and Princes, and regretted by the whole Portuguese people.

His Majesty was elected an Honorary Member of this Institution on the 6th of February, 1877, his certificate stating that: "From his distinguished attainments and exalted position he is eminently enabled to render assistance in the prosecution of public works."

DANIEL ADAMSON was born at Shildon, Durham, in 1818, and in 1835 became a pupil of Mr. Timothy Hackworth—the first man who ever performed the functions of locomotive superintendent to a railway—at the Shildon Works of the Stockton and Darlington Company. Mr. Adamson's pupilage ended in 1841, and he then became a draughtsman in the Shildon works. In 1847 he was made Superintendent of stationary engines, and two years later became Manager under Mr. William Bouch, Hackworth's successor. In 1850 Mr. Adamson became General Manager of the Heaton Foundry, and in 1851 he commenced business on his own account at Newton Wood and Newton Moor Iron Works, near Manchester. Here for twenty years he carried on an extensive business as a manufacturing engineer and boiler-maker until his operations outgrew the capacity of the works. In 1872 he erected, from his own designs, new and more commodious works at Hyde Junction, Dukinfield. These were afterwards enlarged, and exemplified to the fullest degree the modern essentials of an engineering establishment.

Mr. Adamson introduced many improvements in connection with his business, and was in the front rank for activity and enterprise. In 1852 he patented the flange-seam for high-pressure boiler-flues, which is now in general use among boiler-makers, and is known as the "Adamson flange-seam." He also patented improvements in the superheating of steam between cylinders of compound-engines, &c. In 1857 and 1858 he first applied steel in the construction of steam-boilers, and subsequently made more than two thousand eight hundred steel boilers for working at pressures varying from 50 lbs. to 250 lbs. per square inch. In 1858 he patented hydraulic lifting-jacks and improvements in the application of hydraulic power for riveting metallic structures. During 1861 and 1862 he built a triple-expansion compound-engine, and in 1873 quadruple-expansion compound-engines under a further patent for reducing and economising steam. In 1862 he commenced the making of steam-boilers by drilling the rivet-holes through the two plates together after the plates are put into position. This method of drilling holes is now generally demanded in the practice of boiler manufacture. In 1863 and 1864 he erected the Yorkshire Steelworks at Penistone, and was part-owner of the first works in this country that depended entirely on the making of steel on a large scale solely by Bessemer plant. But undoubtedly his principal professional achievement was his share in the introduction of steel as a material for steam-boilers, and the story of his connection with the great advance is best told in Bessemer's own words. At the annual meeting of the Iron and Steel Institute on the 9th of May, 1888, while he held the office of President, Sir Henry Bessemer, at the request of the Council, presented to Mr. Adamson the Bessemer gold medal. Without in any way making an invidious comparison, Sir Henry said the unanimous decision of the Council to award the medal to their President met with his most cordial and entire approval. He recounted how, twenty-eight years ago, Mr. Adamson had induced Mr. John Platt, of Oldham, to let him use Bessemer steel for six boilers under order, and how those boilers were still at work at the time Sir Henry was speaking.[1]

In 1863 Mr. Adamson patented improvements in converters for Bessemer steel. In 1863 and 1864 he introduced improved blast-engines for Bessemer blows. Up to the time of his death Mr. Adamson manufactured all classes of heavy machinery as well as general millwright work and hydraulic machinery, and was sole manufacturer for several American specialities, notably of engines fitted with the Wheelock automatic expansion gear. Mr. Adamson had in recent years patented other inventions, such as compressing machinery, boiler-furnace, and testing machinery, and at his works were manufactured testing machines of from 30 to 2,000 tons power for testing the breaking strength of bridge members and other purposes. Among his recent inventions was a labour-saving arrangement by which as many as twelve tools could be worked simultaneously on a 60-ton lathe-bed. Mr. Adamson also took an interest in the fight between guns and armour-plates, and recently patented a new breech-loading gun, its principal characteristic being a new and effective arrangement of the breech.

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[1] The Journal of the Iron and Steel Institute, 1888, p. 9.

He also from time to time wrote Papers on subjects of interest to the mechanical world, among which may be mentioned one on "Quadruple Expansion Engines," read before the Iron and Steel Institute in Manchester, at its meeting in 1875. At the meeting in Paris in 1878 he read a Paper on the "Mechanical and other Properties of Iron and Mild Steel."

Outside his special vocation Mr. Adamson employed his restless energy in various directions open to a wealthy manufacturer. As a metallurgist he was frequently consulted by persons interested in new speculations. In addition to being at the head of the boiler and engineering works at Dukinfield, he was Chairman of the North Lincolnshire Iron Company, Limited, and of the Newton Moor Spinning Company, Limited, which run two large mills with one hundred and seven thousand spindles.

In official life Mr. Adamson was a prominent figure. He was on the Commission of the Peace for the county of Chester, and was also a Magistrate for the city of Manchester. He was a Director of the Manchester Chamber of Commerce, in whose important functions he took great interest; and he was the President of the Iron and Steel Institute for 1888 and 1889, being one of the original members of that body. At one time he occupied the Presidency of the North Staffordshire Institute of Mining Engineers. He was a member of the North of England Institute of Mining and Mechanical Engineers, a Fellow of the Geological Society, and of various other scientific societies. But that by which Mr. Adamson will be best remembered is his connection with the Manchester Ship Canal, of which he was the virtual founder. On the 27th of June, 1882, Mr. Adamson convened a meeting at his residence, The Towers, Didsbury, the object of which was to consider the practicability of constructing a waterway, which should afford direct communication between Manchester and the great ports throughout the world to which her commodities are consigned. As a result of the meeting, a provisional committee was appointed, with Mr. Adamson as Chairman, to inquire into the whole bearings of the subject, and report upon the practicability of the project. A preliminary fund to cover the cost of detailed surveys was liberally subscribed to, and the project was received by the public with the greatest enthusiasm. The Provisional Committee, after receiving the reports of the engineers, who had been appointed to make the surveys, decided to apply to Parliament for powers to carry out the undertaking; and a Parliamentary guarantee fund was subscribed to cover the expenses of the application. Scores of meetings vere held throughout the city and district, at which the vigorous loquence of Mr. Adamson was heard as he expounded the scheme vith a force and energy born of confidence in its wisdom and easibility. Zeal for the project was infectious, especially amongst he working classes, and in the first stage of the movement the hip Canal was victorious all along the line. To describe the art which Mr. Adamson played in the early stages of the Ship anal undertaking would be to recount the history of that nterprise,[1] which is already well known. When the Ship Canal ill received the Royal assent on the 6th of August, 1885, Mr. damson occupied the post of Chairman of the Directors, and in hat capacity he did much useful work. Two years later, howver, financial difficulties arose which caused Mr. Adamson to etire from that position. In the initial stages of a great comnercial enterprise something more than enthusiasm and engineerng skill is necessary, and the failure of the attempt to float the hip Canal Company naturally led to much discouragement. The *ontretemps* induced many leading men to make a critical analysis f the situation. The conclusion was soon arrived at that it vould be useless to make a fresh appeal to the investing public ntil steps had been taken to place the facts and financial prospects f the Ship Canal beyond reasonable doubt. For that purpose it vas decided to invite a number of prominent citizens unconnected vith the scheme to form a Consultative Committee, to investigate he facts on which the prospects of the company were founded, nd to report its conclusions to the shareholders. This was unoubtedly a critical period in the history of the canal, and great rudence and foresight were necessary. The Consultative Comnittee prepared a report, which was in every way favourable, but ppended to it a recommendation that the Board should be reconructed before any further attempt was made to float the comany. This view was emphasized in the annual report, and everal of the Directors resigned in order to give an opportunity r the policy of reconstruction to be entered upon. Mr. Adamson id not coincide with the report, and when it was subsequently dopted by a large majority of the shareholders at the third nnual meeting, on February 1st, 1887, he retired from the Board. ut although no longer officially connected with the enterprise he ontinued to take the greatest interest in it, and no one rejoiced nore than he when the success of the later arrangements, mainly

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[1] Further particulars concerning the early history of the canal will be found the memoir of Mr. Hamilton Fulton, vol. lxxxvii. p. 418.

through Messrs. Rothschild, for raising the capital, enabled the works to be started.

As may be gathered from the foregoing, Mr. Adamson was a shrewd, hard-headed north-countryman. He was of the stuff of which successful colonists are made, and one of those men who seem specially created to refute those pessimists whose talk is of the decadence of England.

Mr. Adamson was elected a Member of the Institution on the 29th of May, 1877. He died on the 13th of January, 1890.

CHARLES ROBERT ATKINSON, youngest son of Joseph Atkinson, and grandson of Baron George, of His Majesty's Court of Exchequer in Ireland, and some time Recorder of the City of Dublin, was born in Dublin on the 4th of April, 1826. He was educated in England and in Germany, and was articled to Mr. G. W. Hemans, V. P. Inst. C.E., by whom he was subsequently appointed one of the Resident Engineers during the construction of the Midland Great Western Railway between Dublin and Galway. He had charge of the large iron bridge built over the River Shannon, at Athlone, which was then one of the most important bridges constructed in Ireland. Upon the completion of this work, he was employed by Mr. William Le Fanu, engineer to the Kilkenny Junction, Waterford and Tramore Railways, &c. During the greater portion of this engagement Mr Atkinson acted as Resident Engineer on the construction of the Waterford and Tramore line, the works of which he carried out most satisfactorily. During the years 1854 and 1855 he had charge of some important contracts for the late Mr. William Dargan. On their completion he went to India as a Civil Engineer of the first class, in the service of the Honourable East India Company, but, owing to the Mutiny breaking out, he was obliged to return home in 1857. On reaching Ireland he was appointed Resident Engineer of the Sligo extension of the Midland Great Western Railway, having 20 miles of that line under his charge, including the construction of Sligo Station. After the opening of the line to Sligo, he was appointed Resident Engineer on the River Fergus Reclamation-works, where several thousands of acres have been won from the sea. During 1864 and 1865 he was employed preparing surveys, &c., for a railway beween Kilrush and Kilkee. In 1866 he was appointed Chief Engineer on the Ulster Railway, and retained that office until the amalgamation of the line with the Great

Northern of Ireland in the year 1876. Thereupon he was appointed Engineer of the Northern Division of the amalgamation, which comprised the old Ulster system and some additional branch lines. Under Mr. Atkinson's management, improvements were effected in the permanent way, and several important works were carried out, principally the rebuilding of the bridges over the Rivers Carn and Blackwater; also various undertakings in connection with the remodelling and re-signalling of several of the large stations. Owing to ill-health, he was obliged to resign his appointment in August 1889. He enjoyed his retirement only for a few months.

Mr. Atkinson was one of the promoters, and also a director of the Electric Railway between Portrush and the Giant's Causeway, being the first electric railway in the United Kingdom. He took great interest in the construction and carrying out of the line. He was a skilful engineer, with large experience. He was also an accomplished musician, taking part in the orchestra of various concerts in Belfast, especially in connection with the Philharmonic Society. He was a good friend to those subordinate to him in his official capacity, his kind, genial, and generous disposition winning for him many friends from all ranks. He was long connected with Freemasonry, and attained to very high Degrees in the order, contributing also liberally to the various Masonic charities, and he was held in high estimation by the craft.

Mr. Atkinson was elected a Member of the Institution of Civil Engineers on the 6th of February, 1866. He died on the 13th of December, 1889.

FRANCIS ROUBILIAC CONDER, the eldest son of Josiah Conder, well known during his lifetime as a philanthropist and an author, was born a freeman of the City of London, in St. Paul's Churchyard, on 26th November, 1815, and was educated at Mill Hill School. He was articled as an engineer to Sir Charles Fox, in the early days of railway-making in England, and has left some account of his first experiences, and of his personal impressions of men like Robert Stephenson and Brunel, in a volume entitled "Personal Recollections of an Engineer." One of his earliest professional engagements in 1836 was on the Birmingham and Gloucester Railway under Robert Stephenson. Like other members of his profession, he was induced, by the rapid profits of such work, to become a contractor, and was employed by Fox, Henderson and Co., on responsible duties at Birmingham, Pembroke Docks, and Liverpool. In 1848 he took one of the contracts of the South Wales Railway, under Mr. Brunel, the work continuing at intervals down to 1855. In 1850–51, under Fox Henderson, Mr. Conder was employed on the Cork and Bandon Line. These enterprizes brought substantial sums, and enabled him to work independently. In 1854 Mr. Conder was engaged, as a member of the firm of Conder, Goode and Co., in laying the permanent way of the Bordeaux and Bayonne Railway in France, of which work he contributed an account to the Institution.[1] Shortly after he visited Portugal, with a view to railway work, but the negotiations led to no agreement.

In 1855 Mr. Conder undertook a contract for the Brindisi Railway, and unfortunately embarked great part of his fortune in the enterprise, which was well thought of at the time, and under ordinary circumstances might have been extremely lucrative. The Neapolitan Government, under Ferdinand II., was however notorious for its ill-faith; and while the King himself professed the highest interest in pushing on the work, which led Mr. Conder on an adventurous journey through Apulia, the Government placed every obstacle in the way of the fulfilment of the contract, and finally stopped the work by Royal Decree, at the same time appropriating the caution money (£50,000) to its own uses. The various trials which followed led in every case to a verdict against the Government, but without any redress being given; and the serious losses thus entailed led to an attack of brain fever, which incapacitated Mr. Conder at a critical time, and endangered his life. These reverses, due solely to the treachery of the Neapolitan Government, were followed by political events which threw the whole of Italy into convulsions. Mr. Conder witnessed the entry of Garibaldi into Naples; the establishment of Italian unity, and the transfer of the seat of Government to Turin; having vainly endeavoured, on each apparently favourable opportunity, to urge his just claims on the new regime.

In 1864 Mr. Conder was in Turin, but although he had received support from the British Ambassador, the equity of his claims being fully admitted in various letters from the Foreign Ministers at home, he became convinced that nothing more could be done on the spot, and returned to England to take up his profession.

It is not often that a professional man, thus ruined in middle life, has been able to recover his position, and to give his children a good social opening; yet by patience and ability Mr. Conder

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[1] Minutes of Proceedings Inst. C.E., vol. xvi. p. 371.

succeeded in such a task. He became Engineer for a short time to the Bombay Exhibition, and afterwards for many years made an income from literature, during which time he was much occupied in the study of questions concerning water-supply, canals, railway economies, and the purification of sewage, on all which subjects he became an authority, and thus found employment as a consulting engineer.

As early as 1872, Mr. Conder became a regular contributor to the "Edinburgh Review," a connection which continued to the last year of his life, some of his later articles attracting special notice. The subjects were very various, for, in addition to professional knowledge, he possessed a large store of Oriental antiquarian learning. Thus, side by side with articles on canals, railways, harbours, and lighthouses, he contributed Papers on Jerusalem, The Talmud, ("Edinburgh Review," July 1873), and the Monumental History of Egypt. For Mr. George Godwin he wrote every week in the "Builder"; for Mr. Greenwood, his political articles in the "St. James's Gazette" often attracted special notice; for Mr. S. C. Hall, he wrote on Art and Sculpture in the "Art Journal"; and some of his latest and most successful Papers appeared in the "Scottish Review," nearly all the work being, however, anonymous, though in "Fraser" his name became known in connection with the question of railway economies.

One of his most striking contributions to the "Edinburgh" was an article on the Panama Canal, in April 1882, long before public opinion had become instructed as to the real character of that disastrous affair. Mr. H. Reeve, editor of the "Edinburgh," writing to give permission for the authorship of this and other articles being acknowledged, says as follows:—

> "He (Mr. Conder) was the first to demonstrate the impracticability of the Panama Canal on engineering grounds. He was the first to show that the carriage of heavy goods, such as coal, by rail, was a doubtful source of profit, and that the abandonment of canals was a great mistake. He wrote a powerful article on the dangerous tendency of municipalities to run into debt, and many other valuable articles."

Among the most interesting of these to engineers may be enumerated:—

"Edinburgh Review,"	Oct. 1879,	"Civil Engineers of Great Britain."
,,	Jan. 1880,	"British Lighthouses."
,,	April 1881,	"River Floods in England."
,,	Oct. 1882,	"Inland Navigation."
,,	July 1885,	"Harbours and Docks."
,,	April 1887,	"Railway Problems."
,,	April 1888,	"Municipal Debts."

The last article in 1889 was a review of the progress of railway engineering during Mr. Conder's lifetime. Since his death an article on Irrigation in Egypt has been published in the Scottish Review.

Mr. Conder lived to see many of his forecasts verified, and many of the causes he advocated gained. In 1882 he was employed in showing the practicability and the utility of the Manchester Ship Canal. He was consulted as to other canals, and gave evidence before the Royal Commission on the subject of developing this neglected means of transport. On the 6th of February, 1883, he became a Member of the Institution, and his Paper on "Speed on Canals" appeared in the Minutes of Proceedings of the Institution.[1] In 1884 he was consulted on the Metropolitan Water Bill, which, in accordance with his views, was thrown out by a majority of 197 to 152, on the 11th of March in that year.

Mr. Conder was the author of several volumes: "The Trinity of Italy" (a publisher's title), which gives a sketch of his Italian experiences; "Recollections of a Civil Engineer," already mentioned; "The Child's History of Jerusalem;" "The Handbook of the Bible" (Longmans, 1879), and a work of early years entitled "Elements of Catholic Philosophy."

For some fifteen years Mr. Conder paid great attention to the question of the purification and disposal of sewage, which he recognised as a question the importance of which was constantly increasing with increased density of population. His writings did much to turn attention to the question, and at length, in 1885, he discovered a simple chemical process which he patented, and which he described to the Institution of Civil Engineers of Ireland, in May 1888, and to the Royal Engineers' Institute at Chatham, in November 1887. The process was made applicable to private houses, as well as to town-drains, and has already met with considerable success.

Mr. Conder's last professional visit, shortly before his death, was connected with the adaptation of his process to the large town of Halifax. These successes, which promised rapid return to fortune, were due, not to accident, but to a minute study of all that had been attempted for many years in the treatment of sewage, both in England and abroad.

Mr. Conder died very suddenly of angina pectoris, in his study, on the 18th of December, 1889, in full possession of his intellectual powers and activity, having just passed his seventy-fourth birthday.

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[1] Vol. lxxvi. p. 160.

His loss is not only mourned by a large circle of literary, professional, and private friends, by whom he was loved and admired, but will also be felt in English literature, in which he held so high a position.

HENRY JOHN FRASER, the eldest son of the late Mr. John Fraser, of Leeds, was born at Pudsey, near that town, on the 20th March, 1848. He was articled to his father (1866–1870) and on the completion of his pupilage had responsible charge of the works required in the construction of the Bradford, Eccleshill and Idle, and the Idle and Shipley Railways, and from 1874 to their completion in 1879, of the Bradford and Thornton Railways, including very heavy viaduct, tunnel, bridge and other works. He also had charge of the Halifax section of the Halifax, Thornton and Keighley Railways, including a tunnel 1½ mile long. From July 1878 to 1880, he was engaged on the extension of the last named railway from Thornton to Keighley. During this latter period he became a partner with his father, and was also engaged in preparing the designs for the remaining works on the last-named railway, the contract for which was let in October, 1880, including viaducts, tunnels and other works of a heavy character of which he also had personal charge.

Mr. Fraser assisted in the preliminary work and the construction of the extensive system of railways from Newark to Bottesford, Bottesford to Melton, Melton to Tilton, Tilton to Leicester (over 50 miles), and the preliminary work of the Tilton to Market Harborough railways (21 miles). On the death of his father, in 1881, he was joined by his brother-in-law, Mr. W. Beswick Myers, and they, under the name of Messrs. John Fraser and Sons, completed the Thornton to Keighley and Tilton to Leicester sections of the above railways. They also carried out the preliminary work and construction of several other important connecting lines in Yorkshire, viz., the Crofton Branch and the Dewsbury Branch, and had nearly completed the construction of the line from Beeston to Batley, the Harrow and Stanmore Railway, the Halifax High Level Railways, and (in conjunction with Sir Douglas Fox) the Driffield to Market Weighton section of the Scarborough Bridlington and West Riding Junction railways. In addition to the above he and his partner were engaged on several other important railway schemes, amongst which were the Lowmoor to Dudley Hill and the extension of the Pudsey Railway.

Mr. Fraser, who became a member of the Institution on the

2nd of March, 1880, had been in ill health for some time, and died at Ganthorpe House, near York, on the 13th October, 1889, in the forty-second year of his age.

JOSEPH GORDON was born on the 16th of April, 1837, at Haltwhistle, Northumberland, and received there the whole of his schooling, this being strictly confined within the narrow limits then prevailing in English country districts. In 1852 he was articled to the late Mr. James Hogg, then City Surveyor of Carlisle, who enjoyed a considerable range of private practice in the neighbourhood.

Mr. Gordon remained in Carlisle until the death of Mr. Hogg in 1856, when, notwithstanding his youth, he applied, and ran second, for the appointment thus rendered vacant, having by his genial nature and striking abilities won golden opinions from all with whom he had been brought in contact. He was at once selected as an assistant by Mr. Thomas Fenwick, then Borough Surveyor of Tynemouth, but in a few months accepted an offer made to him by Mr. (now Sir) Robert Rawlinson to take part in the preliminary survey for the sewerage works of West Ham, Essex. Ultimately, in 1858, he was entrusted, as Resident Engineer, with the carrying out of Mr. Rawlinson's scheme, an undertaking which that gentleman, writing in 1864, described as including "some of the most complicated and difficult main sewerage works" he had executed up to that time.

In 1860, the City Surveyorship of Carlisle again became vacant, and as the West Ham works were far advanced towards completion, Mr. Gordon applied for the appointment, this time with success. He held the post for six years, and, having by his past experience acquired sound and independent views on sanitary questions, was enabled to find scope for them. Perhaps it was in Carlisle that Mr. Gordon first displayed to the full extent that intense and overmastering love of accuracy and completeness which was, in later years, to form the chief feature of his reputation. His zeal in personally setting out work, and in obtaining none but the highest class of materials and workmanship, became proverbial, and his successful efforts in this direction, even in such matters as roads and footpaths, doubtless encouraged him in his life-long adherence to the methods then pursued.

In 1864, rather than allow him to accept the Borough Surveyorship of Wolverhampton, the Corporation of Carlisle granted Mr.

Gordon the privilege of private practice beyond the limits of the city, a field in which he won his spurs in Parliamentary Committee rooms, in railway and other matters, besides reporting on various projects in the domain of sewerage and water-supply.

In 1866 Mr. Gordon resigned his position at Carlisle, and went to Germany. The city of Frankfort on Main had for some time been considering the drainage question. A committee of engineers and hygienists—amongst them Mr. W. Lindley, the Engineer of the Hamburg drainage works, the earliest and largest works of the kind then executed on the Continent—had, in 1863, been called in to report upon the subject. Mr. Lindley was appointed Engineer of the scheme, and a thoroughly competent man being required to work in conjunction with him in designing and carrying it out, Mr. Gordon was elected by the Municipal Authorities to that position, and acted thereafter as Resident Engineer of the works from early in 1866 to the autumn of 1873.

In this position he worked out in detail and supervised the execution of a large part of the comprehensive system of drainage that has been carried out by the city of Frankfort, in which the thorough flushing and ventilation on the Hamburg system and a careful design and execution of the private drainage form marked features. Stringent conditions and regulations for house drainage were laid down, demanding the presentation of plans, and in every other respect going far beyond what had until then been carried out in this branch of municipal sanitation.

The removal to the Continent was an important step in Mr. Gordon's career, he having to confront an entirely different system to that he had hitherto worked on, while at the same time a foreign language and the continental way of doing things, had to be mastered. By the minute accuracy, care, perseverance, unremitting attention and energy which were peculiar to Mr. Gordon, and which he devoted to the works entrusted to him, he quickly overcame these difficulties, and contributed his share to the high standard of excellence universally accorded to the Frankfort drainage works, and by which they have come to be considered amongst the best samples of works of their kind. Of the Frankfort network of public sewers, which has now a length of upwards of 130 miles, about 40 miles were carried out under Mr. Gordon's supervision, while the lines and details of the whole were established during his period of office.

In 1873 he left the service of the city and became Engineer-in-Chief of the Sewerage and Waterworks Department of Messrs. Holzmann and Co., a well-known contracting firm, which had, up to that time, taken the contracts for a large part of the Frankfort works. In this position Mr. Gordon designed, or was consulted in the design of, the drainage works for various large towns in Germany, amongst others Stuttgart, 110,000 inhabitants; Heilbronn, 24,000; Munich, 220,000; Dortmund, 55,000; Ludwigshafen, 15,000; Nuremberg and Landshut, of which the first five, with an aggregate population of 450,000 inhabitants, were adopted, and have in part been carried out.

Early in 1881 Mr. Gordon returned to England, his election to the Borough Surveyorship of Leicester affording him a welcome opportunity of fulfilling a growing desire to remove his family from residence abroad. He found Leicester in a condition requiring all the skill and energy which even he could bring to bear upon it, the sewerage works having been outgrown by the phenomenally rapid development of the town, besides which the execution of a flood-prevention scheme had become an urgent necessity. Taking in hand the question of floods, and using the gradually-accumulated data and reports as a basis, Mr. Gordon prepared a scheme giving a lower flood-water gradient than had previously been regarded as attainable, and successive contracts were let in accordance with his plans, the total expenditure, up to the time of his resignation, being nearly £300,000, while further contracts were in progress. As regards the sewerage of the borough, one of his first steps was to report on the existence of a ramification of practically unventilated sewers of deposit throughout the town, and to initiate a system of gradually replacing them by a well-devised and comprehensive system of new sewers, together with separate sewers for unpolluted rainfall, so far as these might be practicable and desirable. Coming to sewage-disposal, he prepared a scheme of outfall sewers and irrigation works, at a further estimated cost of £250,000, the execution of which was well forward when he left the Corporation's service, the works including an aggregate of 800 HP. for lifting the sewage to the selected disposal ground, 1,375 acres in extent, this being the largest area in England, and exceeded only by the sewage-farms of Paris and Berlin.

These undertakings were but the leading items of Mr. Gordon's Leicester work, which included, in addition, the ordinary duties of borough surveyor, the preparation of new building by-laws, the inception and detailed conduct of a Borough-Boundaries Extension scheme, and other special efforts necessary to meet the peculiar conditions under which he found the town to be situated. There can be little doubt that the severe and constant strain thus produced proved too much for his naturally slight frame and far from strong constitution, and although the end was deferred until he had entered the service of the newly-created London County Council as their Chief Engineer the undermining of his strength had already gone too far to allow of any different result. He entered upon his new and onerous duties on the 2nd of September, 1889, and on the 9th of November, less than ten weeks later, wa seized with an attack of syncope while in an omnibus on his way from his residence at Hampstead to his office in Spring Gardens, his death being instantaneous and mercifully painless. During his brief tenure of office he had devoted special attention to the pressing question of the main drainage of the Metropolis, and had already presented a valuable report dealing with the working of the new outfall tanks and the disposal of the resultant sludge, on which action has since been taken.

Mr. Gordon's wide and diversified experience and restless activity, combined with his methodical habits, enabled him to compress within the comparatively brief span of his existence a large amount of work of the highest character. His acquaintance with, and devotion to, mathematical research, particularly as displayed in its practical application to hydraulic problems, were of a high order, and these attainments were acquired despite his few and unfavourable early opportunities. He found time, amidst the exacting duties of his Continental life, to actively identify himself with the various technical societies with which he had there become connected, and, soon after his return to England, he joined the Association of Municipal and Sanitary Engineers and Surveyors, a body of which he soon became an enthusiastic and influential member. He filled the office of President in 1887–88, and was elected an honorary member on his appointment to the London County Council Engineership.

For the rest, Mr. Gordon may be described as a favourable example of this country's self-made men, not spoiled by success or good fortune, and regarded with deep respect and firm affection by those whose lot it was to work with or under him. His genial and modest manner never failed to inspire a sense of confidence which was at all times justified by his subsequent performances in the many and varied positions which it was his lot in life to fill.

Mr. Gordon was elected an Associate of the Institution on the 4th of March, 1862, and was transferred to the class of Member on the 17th of February, 1874.

JAMES CAMPBELL LEDGER, born in 1833, was the son of Mr. Z. M. Ledger, a well-known bookseller of Limerick. He was educated at private schools, and in 1854 entered Queen's College, Cork; where he held a Scholarship and took the Gold Medal, "First in Engineering," in 1858. He was apprenticed to the late Mr. G. W. Hemans, V.-P. Inst. C.E., and afterwards continued in that gentleman's employment on works both in England and Ireland till 1868.

In that year he obtained an appointment as Assistant Engineer in the Public Works Department in India; and in October sailed for Calcutta. For the first year of his service in India he was employed on irrigation works in various parts of Bengal; and in November, 1869, was transferred to the Oudh Irrigation Branch, in which he served for three years, being principally employed on the preparation of the Sardah Canal Project. During this period he was promoted to Executive Engineer, 4th grade.

In December, 1872, the execution of the Sardah Canal having been abandoned, he was transferred to the waterworks at Mian Mir, near Lahore, on which he was employed until September, 1874, when he was transferred to the Holkar State Railway, as Personal Assistant to the Engineer-in-Chief. The Holkar Railway, which was originally designed to connect Indore, the capital of the Native State of Holkar, with the Great Indian Peninsula Railway at Khundwa, and thereby with Bombay, was one of the first lines constructed by the Government of India on the metre gauge. It was subsequently extended northwards to join the Rajputana system of metre-gauge lines, thus communicating with Delhi and Agra, the Punjab and North-West Provinces. The works of the Holkar Railway proper included a large bridge over the River Nerbudda, and heavy works on the incline surmounting the Vindhya Hills, which lie to the north of that river. Mr. Ledger worked on this line for three years, obtaining another step of promotion in 1875; but in 1877, having suffered much from intermittent fever, he was invalided home. Weakened as he was by this malady, the cold and damp of the home climate brought on an attack of pleurisy, from the effects of which he suffered for the rest of his life. He remained at home for two years; and on his return to India in October, 1879, he was posted to the Bhopal State Railway.

The Bhopal Railway connects the city of Bhopal, capital of the native state of the same name, with the Great Indian Peninsula Railway, and like the Holkar line, crosses the River Nerbudda and ascends the Vindhya Hills to the plateau of Central India. It is on the 5 feet 6 inches gauge, and now forms part of the Indian Midland Railway, which, by joining Agra and Cawnpore with the Great Indian Peninsula line, makes the shortest route with unbroken gauge from the Punjaub and North-West Provinces to Bombay. Mr. Ledger was in engineering charge of the bridge over the Nerbudda, fourteen spans of 160 feet, and of a large portion of the heavy works in the hills, from the survey to the completion of the work. During this period he was twice promoted, attaining the rank of 1st grade Executive Engineer. He also officiated as Engineer-in-Chief of the line for three months.

In August, 1883, he was transferred to the office of the Director General of Railways, where he worked for two years, and in November, 1885, he was appointed Port Storekeeper for State Railways at Bombay.

In February, 1886, he obtained furlough to England, which lasted till his retirement from the service of the Government of India in December, 1887. For two years his health, undermined by fever and its consequences, gradually grew worse; and in September, 1889, he was taken seriously ill, and gradually sank till his death, which occurred on the 23rd of November.

Colonel Forbes, R.E., under whom Mr. Ledger served while in the Oudh Irrigation Branch, says, "He was one of the best men I have met in the Department—clever, painstaking, and thoroughly acquainted with his work. Most simple and unassuming in manner, and liked by everyone." His Chief on the Bhopal line endorses this opinion and adds:—

"His cheerfulness and courage under indifferent health never failed. He was trusted and esteemed by all who worked with him."

Mr. Ledger was elected an Associate of the Institution on the 6th of March, 1866, and was transferred to Member on the 17th of April, 1883.

JAMES LESLIE, born at Largo, Fifeshire, on the 25th of September, 1801, was the son of Alexander Leslie, architect and builder there. He received the first part of his education at the parish schools of Largo and Newburn, and afterwards at Mackay's Academy, at Edinburgh. In 1815, and for two subsequent years, he attended the Edinburgh University; his uncle, afterwards Sir John Leslie, being then Professor of Mathematics, amd subsequently of Natural Philosophy there. In 1818 young James Leslie was apprenticed to Mr. W. H. Playfair, the well-known architect, who was at that time engaged in the erection of the Edinburgh University buildings, and remained with him till 1824. Although Mr. Leslie did not follow up the profession of an architect, his early training in this line enabled him, from time to time, to furnish with acceptance designs for public buildings, the most important of which are the existing Custom House at Dundee, and Wood's Hospital at Largo. Mr. Leslie early turned his attention to engineering, and in 1824 was taken into the office of Messrs. G. and J. Rennie, Civil Engineers, London, with whom he remained about four years. During that time the greater portion of London Bridge was built, and the bridge over the Serpentine in Hyde Park. He was also engaged under Messrs. Rennie with work in connection with Sheerness Docks, Plymouth Breakwater, Chemillpoint Victualling Yard, West India Docks, and other extensive works.

Mr. Leslie was, in 1828, appointed by the Leith Dock and Harbour Commissioners as Clerk of Works, to carry out, under the direction of Mr. Chapman, Civil Engineer, of Newcastle, the extension of the East Pier of Leith; and he was subsequently employed by the Navy Board to superintend the construction of the West Breakwater of Leith, also designed by Mr. Chapman. While thus engaged, Mr. Leslie began to practise on his own account, and among the first works he carried out were the construction of a wet dock at Dysart, and a coal-shipping pier at St. David's, on the Forth. In 1832 he was appointed Resident Engineer for the Dundee Harbour Works—an appointment unsolicited and unexpected; and almost simultaneously, he was elected to a similar post at Sunderland, which of course he could not accept. He remained at Dundee till 1846; and while there, along with many other important works, he carried out the construction of Earl Gray's Dock, designed by Mr. John Gibb, of Aberdeen, Mr. Telford having originally reported on the whole scheme of improving the Harbour of Dundee. While resident at Dundee, Mr. Leslie carried out a further extension of the East Pier at Leith, under the direction of Mr. James Walker, Past President Inst. C.E., and also designed and executed the wet dock at Montrose, and harbour works at Arbroath, Kirkcaldy, and various other places. He also constructed locks for the Monkland Canal, Glasgow, and a handsome bridge across the River Leven, in Fife. In conjunction with Mr. Jardine, the Engineer of the Edinburgh Water-Works, he, in 1836, prepared the first water-scheme for supplying Dundee from the Monikie district; but the powers of the Act for this having been allowed to lapse, he was again similarly engaged in 1844.

In 1846 Mr. Leslie removed to Edinburgh, and shortly after that he succeeded Mr. Jardine as Engineer to the Edinburgh Water Company, to take charge of their existing works, and also to carry out new works then in progress, and others under a Bill then in Parliament, in conjunction with Messrs. Rendel and Beardmore. In 1849–50, he designed and executed a plan for taking empty boats afloat up an inclined plane at Blackhill, for the Monkland Canal, Glasgow, thereby saving both time, labour, and much water, as compared with the usual method of lockage. This ingenious expedient, which in some measure may be said to have foreshadowed the recently projected ship railways, has been much admired; and in recent years engineers from America and the Continent have visited Scotland to inspect it, with the view of adopting the principle at home.

In 1852, Mr. Leslie, in conjunction with Mr. J. M. Rendel and Mr. Mackain, was Engineer for a scheme for supplying Glasgow from Loch Lubnaig, on behalf of the Glasgow Water Company. This scheme, however, did not pass. The Bill was keenly opposed by the Corporation of Glasgow, who shortly after that took over the control of the waterworks from the Company. They in their turn promoted and carried out the project of supplying Glasgow from Loch Katrine, which had originally been suggested as a desirable scheme by the late Professor Rankine, who, in conjunction with Mr. John Thompson, was the first to realise the important fact that, by tunnelling through the intervening watershed, the water of Loch Katrine could be conveniently introduced into Glasgow. The first of the more important works carried through by Mr. Leslie after his appointment in 1845 as Engineer to the Edinburgh Water Company, by which the Pentlands were drawn upon to provide Edinburgh with water, was that which involved the construction of the Torduff, Clubbiedean, Bonally, and Loganlea reservoirs, and the heightening of the embankment of Glencorse reservoir, originally constructed by Mr. Jardine in 1820. In 1856, under Mr. Leslie's care, the Bill for appropriating the Colzium springs was carried through Parliament, and under its provisions the reservoir of Harperrig, for providing compensation to the water of Leith, was constructed; and in 1863, a further extension from this district was carried out under his superintendence, when the Crosswood springs were utilized, which gave the city an additional million gallons of water per day. In 1868, the question of water-supply in Edinburgh entered upon a very acute stage, and in the following year a keen Parliamentary fight occurred, connected with the taking over of the old Water Company's undertaking by the Corporation. In 1869, the Corporation were successful in taking over the business of the old Water Company, but they lost the works portion of the Bill, which that year was thrown out on Standing Orders. The newly-constituted Water-Trust elected Mr. Leslie Consulting Engineer; and at the same time appointed Mr. J. W. Stewart—who, along with Mr. Bateman, had been associated with the St. Mary's Loch Bill—Resident Engineer. Mr. Leslie was thereafter appointed to report on all the available sources of additional supply for the city, which had already been reported on by Mr. Stewart. The Trustees having received Mr. Leslie's report, again adopted the St. Mary's Loch scheme, and instructed Mr. Stewart again to prepare the necessary plans. A Bill was accordingly lodged for that purpose. Differing from Mr. Stewart as to the probable cost, Mr. Leslie refused to allow his name to appear as engineer of the scheme, and, after having been keenly fought in both Houses of Parliament, the St. Mary's Loch scheme was rejected by the Committee of the House of Lords. After the next municipal elections in the city, Mr. Leslie became sole engineer of the Trust; and in 1873 he and Mr. Hawksley, Past President Inst. C.E., with whom he had for many years been associated in the promotion of water-schemes, and for whom he always entertained the greatest regard and respect, were deputed to report as to the best means of obtaining additional supplies for Edinburgh. They issued a joint report, recommending that the necessary additional water-supply for the city should be obtained from the Moorfoot Hills; and this scheme having been approved of by a plebiscitum of the citizens, the Bill was passed by Parliament during the following year. Under that great scheme, Edinburgh obtained an additional supply amounting to over 8,000,000 gallons per day, and with such a satisfactory result that the Trustees have since, and now are able to distribute the water to the citizens, at a much lower rate than was charged by the old Water Company. Mr. Leslie was also Engineer of the Lintrathen water scheme, under which Dundee obtained from that district an additional daily supply of 8,000,000 gallons of water; and in the promotion of this scheme his hands were materially strengthened by the co-operation of Mr. Hawksley.

Mr. Leslie's advice was frequently sought in reference to the construction of reservoir embankments, and at the time of the Sheffield catastrophe, his specification was frequently quoted as one which might safely be followed in the reconstruction of the works, as well as in reference to the formation of reservoir embankments of equal magnitude both in India and Australia.

ls Engineer of the Paisley Waterworks from 1854, he superntended the supply for that growing centre of industrial life, irst from the classic braes of Gleniffer, and subsequently from the Rowbank district, and from time to time additions have been made o these works by his firm (J. and A. Leslie and Reid), by the atest of which, under an Act of Parliament passed in 1881, a large dditional supply is being made available, the works connected vith which are not yet completed.

Mr. Leslie was connected with the improvement works of most f the towns of Scotland, and acted as engineer, in conjunction vith his partners, for the water-supply of Dunfermline, Berwickn-Tweed, Dunbar, Peterhead, Dalry, Thurso, Irvine, Bathgate, Kirkwall, Galashiels, Bothwell, Hawick, Peebles, St. Andrews, nd many others. He was also engineer for various harbour vorks, including those of Easdale, Stanraer, and West Wemyss.

Mr. Leslie had a reputation as an engineer which was not onfined to this country, his advice having in 1861 been sought in egard to extensive reclamation works at Bilbao, in Spain; and n a subsequent visit to that country he had the satisfaction of eeing the result of his scheme having been carried into effect, nd numbers of houses built upon land over which the sea had ormerly flowed. He was consulted about floating docks at Cadiz, nd by the Indian Government as to the improvement of the avigation of the River Godavery by means of inclined planes, on he principle formerly adopted by him on the Monkland Canal. n 1862 Mr. Leslie was appointed by the Home Office, along with Messrs. W. Ffennell and Frederick Eden, a Scottish Salmon Fishery Commissioner, an office which he held until the institution of the present Scottish Fishery Board in 1882, the duties ppertaining to which he performed to the satisfaction of the uthorities, by whom he was complimented on the conclusion of is term of office. The duties of the commissioners were to fix the oundaries of the districts of every salmon river in Scotland, the ivisions between the upper and lower proprietors, and the limits f the various estuaries; also to frame by-laws for the regulation f the fisheries. Much of this work was not only difficult, but inolved no small amount of fatigue, and even hardship, the greater art of it having to be executed in winter, and in great haste, and ften in very inaccessible districts, and without the assistance of eliable maps. Mr. Leslie's sound knowledge on all engineering natters, and his acknowledged integrity, led to his being requently employed as an arbitrator in important cases of ispute, both in Scotland and elsewhere. He was well acquainted with the leading engineers of his time—Telford, the Rennies, George and Robert Stephenson, the Stevensons of Edinburgh, and many others. In connection with the Forth Bridge recently completed, it is not uninteresting to recall that it was Mr. Leslie who, in 1838, made a report on the best method of establishing a line of ferry boats between the Lothians and Fife. He examined many of the ports on both sides, and as the fruits of his investigations and report, the Burntisland Pier was built by Sir John Gladstone, the father of the ex-Premier, the Granton Breakwaters by the Duke of Buccleuch, and the ferries established which have been worked until the present time by the North British Railway. He lived to see the virtual completion of the Forth Bridge, which is to supersede the old ferries, and in that great engineering undertaking he took the deepest interest. About the time of the "railway mania," as it is sometimes termed, Mr. Leslie was a great deal engaged in this line of business, and although he was engineer for several projected schemes, the most important of which was termed the Glasgow and Dundee Junction Railway, and which, like many others at that time, was thrown out on Standing Orders in consequence of some utterly trivial reason, he never followed it up, but preferred to remain associated with water and harbour works.

Mr. Leslie was a man of very vigorous constitution, and until he had the misfortune to break his leg by a carriage accident, which took place about ten years ago, he was capable of enduring great fatigue, frequently starting at six in the morning and returning late at night, after doing work which few younger men would have cared to undertake. He was well read in engineering literature, and no member of his profession was more respected by his brethren. He also enjoyed the esteem of a very large circle of private friends. He was a Liberal in politics, and took an active, though not a prominent part in all public and political matters. He continued Engineer to the Edinburgh Water-Trust until his death, he having in 1870 associated with himself in partnership his son, Mr. Alexander Leslie, and latterly his son-in-law, Mr. R. C. Reid. By this he was of course latterly relieved of much of the work of the office, although until near the end of his life he continued to give his valued advice in the more important matters connected with the business.

Mr. Leslie was connected with the Institution for more than half a century, having been admitted as a member in 1833, and at the time of his death he was the "father" of the Institution. He was also a Fellow of the Royal Society of Edinburgh, and various other learned societies, including the Meteorological Society of Scotland, in which he continued to the last to take a deep interest, and from his own observations on rainfall, evaporation, and absorption, was enabled to contribute much valuable information to the literature of that body. A man of generous disposition, Mr. Leslie was a liberal subscriber to every public purpose that approved itself to him, and he also gave largely to charitable institutions, as also to private wants. In spite of his serious accident, he continued daily to take exercise, though with much difficulty, and he occasionally paid visits to the various reservoirs in the neighbourhood of Edinburgh, the welfare of which he seemed to have at heart. He was, however, entirely confined to bed for the last six months of his life, and endured no small amount of suffering, which he bore with patience and even cheerfulness. He died on the 29th of December, 1889, in the 89th year of his age.

ROBERT WATSON LUNN was born in Lincolnshire, on the borders of the Fens, with which his name and work were connected during a large portion of his life. His first introduction to business was in association with Messrs. Thornbury and Harding, who were the contractors for the construction of the main drain in the Middle Level, one of the three divisions of the great level of the Fens called the Bedford Level. Under Acts of Parliament, passed in 1844 and 1848, a new and successful system of drainage had been introduced by Mr. James Walker, Past President Inst. C.E., and the drain in question was the channel by which the water of 140,000 acres of fenland was conveyed into the Ouse at the upper end of the Eau Brink Cut and thence through King's Lynn to the sea. The main drain is one of the finest works of the kind in the kingdom, and it runs in an almost straight line for a distance of nearly 12 miles; the width of the cutting is from 100 to 150 feet; it is of course embanked, and the distance from bank to bank much increases the apparent width of the watercourse. Standing on one of the numerous bridges and remembering that the river is artificial, the spectator must go to Holland to see anything more striking. This Cut will be remembered by hydraulic engineers in connection with the sad calamity of 1862, viz., the bursting of the outfall sluice, which stood flush with the bank of the Ouse at the point where the drain enters the tidal river, and in connection with the temporary drainage of the large district by means of siphons. It is also associated with the new outfall sluice erected by Sir John Hawkshaw, Past President Inst. C.E.

After the completion of the Middle-Level works, Mr. Lunn, still with Messrs. Thornbury and Harding, assisted in the reconstruction of the Black Sluice at Boston in Lincolnshire, and afterwards became a contractor on his own account within the limits of the Middle Level.

When the works of the Middle Level were so far completed that a resident engineer became necessary, the attention of the Board was directed to Mr. Lunn, whose merits as an able, practical, thorough man of business, had become widely known to those interested in the drainage of the Fens, and he was accordingly, in August, 1853, appointed Superintendent. From the date of his appointment until his death, which took place in the town of March, he never lost the confidence of his employers, and was much esteemed by Sir John Hawkshaw, who, after the death of Mr. Walker, became the chief engineer of the level.

The life and experience of Mr. Lunn in connection with the Middle-Level drainage, including the final separation of the Middle Level from the Bedford Level in 1862, is the history of that undertaking during the like period. There were probably few men better qualified than Mr. Lunn to undertake such duties as those assigned to him. He was thoroughly acquainted with the details of bridge- and sluice-building, a most important part of his business, considering that he had 100 miles of rivers under his control. He was almost unrivalled in the management of the large bodies of excavators, whose services he had from time to time to engage. As a man his integrity and conscientiousness in the performance of his duties were proverbial.

Mr. Lunn was elected a Member of the Institution on the 4th of April, 1871; he died on the 13th of March, 1890, in his seventy-fifth year.

WILLIAM JARVIS McALPINE, an American engineer of the highest eminence—long distinguished in his own country for the number and difficulty of the works he has executed—but whose repute latterly extended to both sides of the Atlantic—died at his house in New Brighton, Staten Island, New York, on the 16th February, 1890, at the age of seventy-eight.

Those who most intimately knew Mr. McAlpine can best understand that the high appreciation in which he was held, and the sentiments of esteem and regard which he invariably inspired, did not come without adequate cause, as they would know that he was not more distinguished as an engineer for the boldness, originality and safety of the works he designed, than as a man for the urbanity, benevolence and integrity that uniformly influenced his conduct. Mr. McAlpine was the eldest son of John McAlpine. He was born on the 30th of April, 1812, in New York City. His grandfather, Donald McAlpine, was a lieutenant in the 42nd Highlanders, "Black Watch," and afterwards captain in the Queen's Guards. Donald traced his descent, in unbroken line, from the Scottish kings of the Clan Alpine. He married Elizabeth Storer, of Beaufort, South Carolina, U.S.A., where his son John was born, 1783. John was a mechanical engineer. He married in 1811 Elizabeth Jarvis, a direct descendant of Admiral Jarvis, Lord St. Vincent, and granddaughter of Bishop Jarvis, of Connecticut, U.S.A.

In 1827, young William McAlpine commenced the practice of engineering under Mr. John B. Jervis, the best known American engineer of that day, and he remained with Mr. Jervis in various advancing grades until 1839. Thence, until 1844, Mr. McAlpine was the Chief Engineer of the Erie Canal enlargement; next for five years Engineer-in-Chief of the United States Dry Dock at Brooklyn. He was subsequently Engineer of the Water Works at Albany, at Chicago, at Buffalo, and other places. In 1851 he was appointed to the office of State Engineer and Surveyor General of the State of New York, and in 1853 he became Engineer of the Erie Railway, in 1857 of the Galena and Chicago Railway, and in 1859 of the Harlem Bridge. In 1861 he became Vice-President and General Superintendent of the Ohio and Mississippi Railway. In the course of his practice he was Chief Engineer of upwards of 500 miles of railway and 200 miles of canals with their bridges, canal-locks, aqueducts, etc. During the American Civil War Mr. McAlpine received a Government appointment in the State of Ohio, to protect certain fortifications, and to arrange for the rapid transportation of troops.

For many years Mr. McAlpine was the Chief Engineer of the Arcade Railway of New York. In 1868 he was elected President of the American Institution of Civil Engineers—an organization of which he was one of the most influential founders, and to which office he was re-elected. In 1870 he was requested by the Emperor of Austria to report on the improvement of the Danube. His plans were accepted in preference to the alternative plans propounded by some of the most eminent European engineers. He was also the engineer of the proposed inter-oceanic railway of Tehuantepic, intended to connect the Atlantic and Pacific oceans. Mr. McAlpine had very early examined the Isthmus of Panama, and had satisfied himself that no canal could be there profitably made. The main ground for this opinion, which he gave to the writer of these lines, was, that at a certain period of the year such a deluge of rain falls in that region that it sweeps off every loose thing from the surface of the ground, and that at this season so much water carrying sand would sweep across the canal that it would, in a brief time, be filled with sand, which would have to be dug out before navigation could be resumed.

One of the leading features of Mr. McAlpine's practice was that it was not empirical, but that the remedy varied in its nature with the character of the ailment which had to be confronted. Thus, in preparing the foundations of the great dry dock at New York, it was found that certain spots consisted of quicksand with springs of water in parts. Mr. McAlpine devised a very simple remedy which was perfectly effectual. Vertical pipes were sunk at the points where the springs were, so that all the water came up through the pipes, and this point having been attained, the pipes were lengthened upward, so as gradually to raise the head of the water transmitted through them. With every increase in the head the upward current in the pipes became less and finally ceased; or by pouring water into the pipes the current might be reversed or made to flow downward into the earth at the points whence it had first emerged. This simple device was perfectly successful. The springs in a short time puddled themselves, and the work of construction was thus enabled to proceed.

Of all the departments of general engineering science, hydraulic engineering is probably that which involves the largest number of difficult problems; and in the whole compass of hydraulic engineering there is no operation involving a larger sense of responsibility than the design and construction of the earthen dams placed across rivers for the storage of water. From the occasional failure of some of these dams, great loss of life and a large destruction of property have been from time to time produced, and an adverse feeling in regard to such dams has thus been created which has greatly circumscribed their employment. Exception, however, was made of Mr. McAlpine's dams. Among them there have been no failures, and it was known that in them special expedients of security had been adopted which were not employed elsewhere. What those expedients are it may be useful here in a few words to explain.

The most usual cause of the failure of earthen dams is traceable to the imperfect contact of the dam and the ground upon which it rests, and if there be sluice-pipes or other pipes passing through the earthwork there may be imperfect contact between the earthwork and the outsides of those pipes. If from any such cause a leak, however small, should occur, then the high velocity of the water due to the lead usually employed erodes the earthwork and increases the leak until it becomes dangerous, and eventually the dam gives way. Mr. McAlpine's practice—after removing the superficial soil, where the dam had to stand—was to make sure that the foundation was sound. If there were loose or cracked and contorted rocks they were removed to a sufficient depth to enable the dam to stand upon an impervious basis. But the most important feature of the construction was that the whole width of the foundation was divided into seven or nine parallel trenches, of which the central one was the deepest and the trenches on each edge the shallowest, the intermediate trenches being of intermediate depths. In a dam formed on this plan there is such an amount of loverlap between the dam and the earth that leakage is not probable, and even if it did occur it would not be likely to inflict serious injury, inasmuch as the stream of the ejected jet has to turn so many right-angled corners before its final escape that its momentum is much impaired, and its erosive action correspondingly diminished. Sluice- or other pipes penetrating the dam were provided with a number of large flanges at intervals or a few feet, and precaution was of course taken to make sure that the earth was carefully rammed against the pipes and between the flanges. Such additions to the structure add little to the cost and render the security almost perfect.

Mr. McAlpine was a member of various scientific societies both in his own country and in Europe. In 1869 he was awarded a Telford medal by the Institution for a Paper on the Supporting-power of Piles.[1] He was the author of about fifty books, pamphlets, reports and other printed papers, illustrative of important topics in practical engineering; and all his works, whether literary or constructive, will be found to be safe guides in practical engineering. He was elected a Member of the Institution on the 5th of March, 1867, being the first American engineer to join the English professional society.

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[1] Minutes of Proceedings Inst. C.E., vol. xxvii. p. 275.

During Mr. McAlpine's later years he made several visits to Europe, and his connection with this Institution was of the most intimate and friendly character. By its officials he will always be remembered as a courteous, kindly gentleman, ever ready to impart information from his own rich stores for the benefit of others, and eager to acknowledge his obligation if chance enabled them to reciprocate some of his favours.

WALTER MONTGOMERIE NEILSON,[1] son of Mr. James Beaumont Neilson, the inventor of the hot-blast, was born in Glasgow in 1819. Having received a sound practical education, he was trained as a mechanical engineer in the works of his uncle, Mr. John Neilson, of the Oakbank Foundry, and under Mr. John McAndrew, in the St. Rollox Engine-Works, Glasgow. While a very young man, somewhere about the year 1840, he entered into partnership with the late Mr. Kerr, in the establishment which has since become so widely known as the Hyde Park Locomotive Works. At first the business of the firm was confined to land and marine engines; but about 1842 they began to turn their attention to the construction of locomotives, an industry which was then, comparatively speaking, in its infancy, but in which there were already several firms in Glasgow engaged. In 1852 the construction of marine engines was added to that of land and locomotive engines, but shortly thereafter the first and second of these branches were dropped, and the firm devoted all its attention to the development of its railway connection, their efforts in this direction soon attaining complete success. In 1857 Messrs. Neilson and Co.'s connection with Indian railways commenced, and in this important market they attained the first place amongst locomotive builders. During the course of this connection, Mr. Neilson's firm constructed fully twelve hundred engines for the railway service of that Dependency, and the many and varied types included in that number would of themselves form a most interesting and instructive chapter in the history of the locomotive industry. In addition, the name-plate of the Hyde Park Locomotive Works is largely to be seen on the home and continental railways; on those of Africa and South America, as well as of the British Colonies all over the globe.

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[1] The substance of this notice is from the *Kirkcudbrightshire Advertiser* of July 12, 1889.

By the death of his father in the year 1865, Mr. Neilson succeeded to the residential estate of Queenshill, in Kirkcudbrightshire, and retiring from business in 1878, he removed thither, intending to devote himself to less exacting pursuits. But he was never able to take much interest in the occupations of the country gentleman, and he frequently revisited Glasgow, the scene of the labours of his active years. Mr. Neilson was a Commissioner of Supply for the Stewartry. In addition to the estate of Queenshill, he also possessed the property of Barcaple, Valleyfield, Largs, and Trostrie, a very large number of feus, &c.

Mr. Neilson was an enthusiastic supporter of the Volunteer force, and was for many years colonel of the 6th Lanarkshire Corps. He was also a prominent member of the order of Freemasons, and held office as Grand Master of the Glasgow Province. In politics Mr. Neilson was a Liberal. When the recent split in the party took place, he threw in his lot with the Liberal Unionists. He was a member of, and latterly an office-bearer in, the Free Church. For a number of years Mr. Neilson has been in the habit of spending the winter in Italy. He had an estate called Monte Picini, near Florence, in the development of which he took great delight, conducting elaborate experiments in the culture of the vine. In summer he returned to his country seat at Queenshill. At the end of 1888 he had an attack of paralysis, to which he gradually succumbed, death occurring on the 8th of the July following.

Mr. Neilson was elected a member of the Institution on the 3rd of April, 1860.

ROBERT RING, the eldest son of Mr. David Ring, architect and builder, of Templemore, county Tipperary, was born on the 30th of September, 1846, and received his earlier education at Fermoy College, county Cork. In October 1862 he entered Queen's College, Cork, gaining an exhibition at the examination for scholarships at entrance. In his second year, at the Sessional Examination, he gained fourth place and certificate in Natural Philosophy, and third place and certificate in Engineering. In his third year he gained third place and prize in Applied Natural Philosophy, and second place and prize in Engineering. At his first university examination, in 1865, at the Queen's University he got third class honours, and at the final examination for the diploma (afterwards converted into the degree of B.E.) in 1866, he again obtained third class honours. In 1867 he entered for the open competition for appointments to the Indian Public Works Department, and passed successfully, receiving his appointment in July of that year. He then proceeded to India, and on arrival was posted in the grade of Assistant Engineer to Burmah, in which province he passed the whole of his subsequent service. He was promoted to the grade of Executive Engineer in October, 1874, and to that of Superintending Engineer in December 1888.

The works on which Mr. Ring was employed during his long service in Burmah were of a very varied kind. They comprised roads, buildings, canals, river-improvements, and even barracks and fortifications, as there was no Department of Military Works in Burmah. In 1885, when circumstances arose which rendered it necessary to take immediate steps for the defence of Rangoon against possible attack from the sea, the remarkably prompt and good work done by Mr. Ring received very special commendation both from the military authorities and the Government. In 1886 his health began to break, and early in 1887 he was obliged to take a year's leave to England, which he afterwards had to extend to twenty months. On return to Burmah in 1888, he was sent as Superintending Engineer to Mandalay, which has a much drier climate than Rangoon, and here he seemed for a time to be in a fair way to regain his old health and strength to an even greater degree than he had done in England. But his long residence of more than twenty years in the hot, damp climate of Rangoon laid the seeds of the disease which ultimately caused his death. While at Mandalay, he had been able to make several successful tours of inspection to the Ruby Mines, the Shan States, and elsewhere. He had returned to his headquarters to take part in the preparations for the reception of Prince Albert Victor; and it was after these had been successfully accomplished that acute symptoms of his malady set in and he died somewhat suddenly on the 2nd of January, 1890. The following notification was published in the *Burmah Government Gazette* on the 7th of January, 1890:—"No. 4.—The Chief Commissioner has received, with deep regret, the intelligence of the death at Mandalay on the 2nd of January, 1890, of Mr. Robert Ring, M. Inst. C.E., Superintending Engineer of the 3rd Circle. Mr. Ring had served in Burmah for more than twenty-two years, and, by his knowledge of the language and his intimate acquaintance with the character of the people and with the modes of construction prevalent in the province, was specially qualified for the appointment of Superintending Engineer at Mandalay. The Chief Commissioner desires to express his appreciation of Mr. Ring's value as a public servant, and his great regret at his death in the prime of life and at a time when his ripe experience was of so much use to the Administration."

Mr. Ring was elected a Member of the Institution on the 23rd of May, 1882.

CUBITT SPARKHALL RUNDLE, born on the 24th of May, 1818, was the son of Captain George Rundle of Maker, Cornwall, and the nephew on his mother's side of the late Sir William Cubitt. He began life as a sailor, and eventually commanded several ships in the merchant service. One of his logs, describing a very severe cyclone through which he successfully navigated his ship, was quoted with much approval by Piddington, in his "Laws of Storms," and is evidence of the faculty of scientific observation possessed by the young skipper. In 1851 he left the seafaring life, and turned his attention to engineering, for which he evinced a strong predilection and natural aptitude. He began his professional career on the East Indian Railway as personal assistant to Mr. George Turnbull, the Chief Engineer, and subsequently in 1855 set out 100 miles of the above Railway, and was engaged in the design and construction of the bridge over the Keeul, at Lucki Serai. A testimonial presented to him at about the same time by his subordinates on the Keeul Bridge is evidence of the esteem in which he was held by those working under him, and of the kindly interest that he always took in their welfare. On his return from a well-earned furlough in 1860, he was appointed Transport Superintendent in the service of the East Indian Railway Company, and was entrusted with the construction of a considerable fleet of transport vessels, steamers, and barges for the conveyance of material by river to different points on the line, and on the successful completion of this work was offered a post as Traffic Manager, which, however, he declined. He subsequently entered into partnership with Mr. Herschel Deas of Monghyr, and was engaged in the exploitation of the Himalayan forests for the supply of sleepers to the East Indian Railway. In this work he displayed his usual energy, and gained much valuable experience; but, being at heart an engineer, he desired to return to duties of a more strictly professional character, and in 1869 accepted an appointment as Executive Engineer in the Indian Public Works Department, which was offered to him by General Sir Richard Strachey. Mr. Rundle was posted to the Punjab, and placed in charge of a Special Survey Division for the survey of the Native States Branches of the Sirhind Canal, with a large staff of assistants. He was subsequently employed on the construction of their branches, with headquarters at Patiala. The prosecution of these works, which lay entirely in the territory of the three Phulkian States, Patiala, Sind, and Nabha, involved constant negotiations with the Durbars of those States on all matters connected with the acquisition of land, and the supply of labour and materials. For the conduct of this work, Mr. Rundle was specially appointed as Canal Agent for the Cis-Sutlej States, the duties of which office he carried out in addition to his purely executive work. The post was a difficult one, but his honest and straightforward character and kindly tact soon secured for him the confidence both of the Government which he represented, and of the Native Chiefs, whose interest he had always strongly at heart. During his residence at Patiala he was also engaged on several important State works, chief of which were the drainage works for the protection of the city from the floods in the Patiala Nullah. He also designed a very comprehensive scheme for the internal drainage of the city, which has not, however, yet been carried out. Mr. Rundle's services were so much appreciated by the Indian Government that he was allowed, as a special exception to departmental rules, to retain his appointment long after attaining the age of fifty-five years, but on the occasion of the reductions in the Public Works Establishment in 1879 he accepted the special retiring terms then offered, and resigned his departmental appointment. Although then in his sixty-second year he was still full of work, and shortly after accepted an appointment as State Engineer to the Kapurthala State, a post for which his previous experience at Patiala peculiarly fitted him. The principal works designed and executed by him during the ten years for which he held this appointment were the weir across the Beyer River, and the Causeway Bridge, which he also carried out, from the designs of a predecessor, the Kapurthala Durbar Hall, a very handsome structure, which is the envy and admiration of all the neighbouring States. In 1889, he at length retired from office, with the thanks of the Raja and officials, and after completing all the public works that had been entrusted to him during the minority of the former.

At the time of his final retirement into private life, Mr. Rundle was in the enjoyment of excellent health and vigour, which were alike remarkable after so long a life of arduous work in an Eastern climate, but in July 1889 he suffered from a sunstroke followed by severe fever. He rallied for a time, but never fully recovered his strength, though he continued to take as keen an interest as ever in the topics of the day, was ever ready with a cheerful joke, and full of the kind thought for others, which was one of the most marked characteristics by which he was endeared to his family and friends. He gradually, however, grew weaker, and finally sank, after three days' illness, dying quietly and without pain, at Amritsar in the Punjab, on the 24th of December, 1889, and in the seventy-second year of his age.

Mr. Rundle was elected Member of the Institution on the 6th of December, 1865.

WILLIAM HERON STEEL was born in Glasgow on the 13th of March, 1830, and was educated at the High School of that city. In 1845 he began his training as an engineer under the late Mr. Andrew Macfarlane, one of the most exact professional men of his day. In 1853 he entered into partnership with a fellow pupil, Mr. Thomas Wharrie. He acted for some time as assistant to Mr. Joseph Cochran, engineer on the Monkland Railways, and towards the end of 1855 his medical advisers recommended a voyage to India or Australia, his health having temporarily suffered from undue exposure. He arrived in Melbourne in February, 1856, and found the climate suited him so well that he resolved to remain in the colony, much to the regret of his friends and professional brethren, all of whom looked forward to his taking a high position in their ranks. His subsequent career rapidly proved how just was their estimate. In three months after his arrival in Melbourne he became assistant to Mr. C. Hodgkinson, then consulting engineer to the newly-formed municipalities. On the 1st of August, 1857, he entered the Public Works Office, to undertake the engineering work in connection with the many piers, jetties, and harbours being commenced along the coast. In a year or two afterwards he had the entire charge of the engineering branch of the Public Works Department. Mr. Wardell was the inspector-general until the time known in Victorian Annals as "Black Wednesday," when Mr. Steel was appointed. In that office he remained until his death.

With ready tact and great natural ability, he was an able administrator. A man of the highest integrity, he was able to hold the balance between the Government and its contractors, and to act as an arbitrator when any dispute arose. The strictly impartial justice which characterized his decisions was always recognized. Although in control of the public works, his special interest lay in maritime engineering and the construction and improvement of ports and harbours. He threw himself heartily into the execution of all important works, especially the bay and port fortifications. The clearness of his judgment in harbour works is borne witness to by the fact that his proposals, with but slight modifications, were approved of by Sir John Coode, President Inst. C.E. Appointed in January 1878 as Inspector-general of Public Works and Chief Engineer of the Melbourne water-supply, he for some years acted as Chief Engineer of Victorian water-supply, until a separate department was formed. Among the important public works he designed or superintended are the Alfred Graving Dock, Prince's Bridge, Falls Bridge, Parliament House, the new Gippsland Lakes Entrance, the Belfast Harbour Improvements, the Warrnambool Breakwater, the Portland Breakwater. The defence works he took a great pride in, and the skilled military experts who have from time to time reported on them have been lavish in their compliments on the marvellously cheap and yet thoroughly effective methods he had adopted, particularly at the Heads and the South Channel Fort. The new cut at Fishermen's Bend, and other harbour works were carried out under his auspices. Mr. Steel during his busy life—busy in the public interest—found time to act as a member of the board on whose recommendation the recent extensions of the Melbourne water-supply system were resolved upon—the Wallaby and Silvery Creeks and the Watts River Aqueduct. He also undertook the guidance of the deliberations of the Swamp Board appointed under the Land Act, 1884, to reclaim the Kowee-rup, Moe, and Condah swamps, which cover an area of 90,000 acres. As far as Condah Swamp is concerned the work is pretty well completed, and the others are being proceeded with on the lines suggested by Mr. Steel. He had collections of documents and newspaper cuttings in relation to the initiation of all the public works of the colony covering a period of the last twenty-five years. These documents were all carefully indexed and arranged, and were thus readily accessible. In the public service he was deservedly beloved, and the blank caused by his premature death will not be easily filled.

Mr. Steel was elected an Associate of the Institution on the 5th of December, 1871, and was transferred to the class of members on the 12th of January, 1886. He died on Christmas Day 1889.

HUTTON VIGNOLES, second son of Mr. Charles Blacker Vignoles, F.R.S., Past President Inst. C.E., was born on the 18th of November, 1824, just after his father had returned from

America, and had taken up the work of a civil engineer in England. In 1836 he was sent to school at the village of Menars, near Blois, France. Here he remained till 1841, in which year he became apprentice for six years to Mr. (afterwards Sir) William Fairbairn, of Manchester. In 1843 he was with his father, surveying for the Würtemburg Railway. In 1845 he was associated with his father in the plans for the North Kent Line, and about thirteen other railways. At this period the race against time for depositing plans for session 1846 was at its height. For nearly a week not one of Mr. Vignoles' staff went to bed!

Early in 1847 Mr. Hutton Vignoles undertook his first journey to Russia, and, after his father had secured the concession for the great suspension-bridge over the Dnieper, at Kieff, he was appointed its Resident Engineer. The work was of great difficulty; the floods were most violent, and the foundation nothing but sand; and in 1849 the foundations of the bridge were swept away. This trouble was ultimately overcome by the use of fascine mattresses. The difficulty of obtaining men was very great, and material had to go by sea to Odessa, and thence over rough roads 300 miles to Kieff; and, in addition to all this, in 1848 cholera appeared and caused great havoc among men and staff. However, all difficulties were finally surmounted, and in 1853 the bridge was opened, with great pomp and ceremony, by the Russian authorities. This suspension-bridge was, at the time, the largest in the world, and still remains among the most handsome; and it withstands, though founded on nothing but shifting sand, the shock of the wild and tumultuous floods that beat against it every spring when the ice breaks up.

From 1853–55, Mr. Hutton Vignoles was Resident Engineer on the Frankfort-Wiesbaden-Cologne Railway, and in 1856 left Europe for Brazil. Here he was engaged at first in making roads in the interior of the province of Bahia, a wild and totally uncivilized country. Then he made the surveys for the Bahia and São Francisco Railway, which he finally constructed. These works kept him in Bahia till 1864, in which year he returned to England, and became Engineer in England for the Warsaw and Terespol Railway. From 1869 to 1872 he was occupied in designing and constructing the Leipzig tramways, for which he was sole Engineer.

Mr. Vignoles' work led him into varied scenes, and his life was full of interest; but no doubt all his exposures and hardships told on his health. He left England in 1884 for the country-house in France, where he passed the closing years of his life. For many years his strength had been on the wane, and on his return to England in 1889 he was taken ill, and, after more than six months' decline, died on December 14th, 1889, with twelve of his children around him.

He was of a taciturn disposition, though his varied experience made him a mine of information; and his name will be remembered as that of one who was never associated with anything which was not above-board and straightforward—a man of steadfast honesty and integrity. He was elected a member of the Institution on the 20th of May, 1854.

WILLIAM WILLCOX was born at Areley, Staffordshire, January 18th, 1830, and was educated at Park School, Bewdley. He studied engineering under Mr. Stephen Ballard and Mr. Samuel Willcox (his brother), who carried out important contracts for the late Mr. Brassey. From 1860 to 1863, Mr. William Willcox was engaged on the Melbourne and Castlemaine Railway, in Victoria, and was on his brother's staff in constructing railways in New South Wales. In 1863 he returned to England, and from that time until 1869 was in charge of works for Messrs. Brassey and Ballard, upon the Evesham and Ashchurch Railway and on the London and Bedford portion of the Midland Railway. In 1870 and 1871, Mr. Willcox was District Engineer on the East Hungarian Railway for Messrs. Waring Brothers; and from 1872 to 1874 he was engaged in the survey of the Parana and Matto Grosso Railway, in Brazil. In 1874 Mr. Willcox went out to South Africa, and from that time to 1883 was engaged in carrying out surveys and railway works for the Government of Cape Colony. In 1885 he constructed the section of the Kimberley Line from Orange River to Modder River; on its completion, in consequence of the suspension of railway work in South Africa, Mr. Willcox turned his attention to gold-mining, but he did not meet with the success which he anticipated in his new enterprise, and when railways were recommenced he undertook the surveys in the Free State on the lines from Colesberg to Bloemfontein, and from Harrismith to the Natal border. It was while engaged upon the latter survey that he caught a cold, which he neglected in his anxiety to push on the surveys; pneumonia supervened, and he died at Harrismith, August 14th, 1889.

Mr. Willcox had a good practical knowledge of his profession, and possessed a remarkable faculty in the selection of country, which proved most valuable to him in his varied Colonial railway experience. He was elected a Member of the Institution on the 4th of March, 1884.

CHARLES FREDERICK von BIBRA was born in India on the 15th of November, 1844. He began his professional career as a pupil of Mr. J. B. Nelson, under whom he was employed until 1867 on various railway surveys, designs for public buildings in Central India, the Municipal Railway of Calcutta, and other works. He then joined the staff of Messrs. Brassey, Wythes, and Perry, and was employed on the construction of the Chord line, East Indian Railway. Mr. von Bibra's next appointment was that of Superintendent of Drainage and Waterworks at Calcutta, under Messrs. Clarke, Anley, and Smith. While thus occupied he built the Wellington Square reservoir. In 1869 he entered the service of the Eastern Bengal Railway Company, and was employed under Mr. (now Sir) Bradford Leslie, and Mr. Ernest Benedict, in charge of important works of construction and maintenance. In 1870 he left the Eastern Bengal Railway, and entered into partnership with Mr. Thomas Mitchell, of Calcutta, as a contractor, and with that gentleman constructed the Porada Branch connecting the Eastern Bengal Railway with the Northern Bengal State Railways, with locomotive workshops for the latter line. As a contractor he was also concerned in the Darjeeling Himalayan railway-bridges and warehouses for the Eastern Bengal Railway; the Northbrook Memorial Hall, Dacca, and municipal buildings at Calcutta. In 1880 he dissolved partnership with Mr. Mitchell, and joined Mr. Robinson Souttar, as Resident Engineer and Superintendent, for the construction of the Calcutta Tramways. On the completion of the latter undertaking, Mr. von Bibra became an extra Resident Engineer on the East Indian Railway, and was employed on special works till the end of 1887. He then again joined Mr. Mitchell; but failing health compelled him to give up work in 1888, and, growing gradually worse, he died on the 1st of April, 1889.

Mr. von Bibra learnt his business in the school of practical experience, being one of those useful men who, born in India, have a thorough knowledge of the habits, languages, &c., of the natives. Being a gentleman by birth, nature, and education, he was invaluable in dealing with native contractors. He joined the Institution as an Associate Member on the 4th of December, 1883.

ANTONIO LUPICINIO BUARQUE was born on the 21st of March, 1854. After being educated with a view to the profession, he obtained his licence as a Civil Engineer from the Polytechnic School of Rio de Janeiro, in 1874, and in December of that year was nominated Constructional Engineer of the Railway and Road between Carytiba and Assunguy, in the province of Paraná. On the 12th December, 1876, he was transferred, as Directing Engineer of the District Lands and Colonization in the Province of Paraná, at the same time assisting in determining the limits of the same Province with that of São Paulo. On the 19th June, 1878, he was posted Constructing Engineer of the Baturité Railway in the Province of Ceará.

In March, Dr. Buarque became Resident Engineer of the Paulo Affonso Railway, in the Province of Alagoas, which post he occupied for the ensuing five years. In 1884 he was made Sectional Chief of the Commission for the Surveys of the Madeira and Mamoré Railway in the Province of Amazonas.

A year later, he was removed to the post of Assistant Engineer Fiscal of the Great Western of Brazil Railway, in the Province of Pernambuco, and in March 1886 was promoted to Resident Engineer of the Paulo Affonso Railway, in the Province of Alagoas, where he held the combined posts of Traffic Manager and Locomotive Superintendent. But he only fulfilled these duties for a few months, being, in the following December, nominated Constructing Engineer on the Prolongation of the Recife and São Francisco Railway, and on the Curuaru Railway, in the Province of Pernambuco, which post he occupied until his death, on the 31st of August, 1888.

He was elected an Associate Member of the Institution on the 6th of December, 1887.

FRANCIS SHELDON CHITTENDEN dated his connection with the profession from 1869, when he became Assistant to Mr. George Kilgour, then District Engineer at the Klausenburg end of the Grosswardein and Klausenburg line, now forming part of the Hungarian State Railways. On the partial suspension of these works, he went to the Cape, where he was engaged in the Government Railway Service until 1880. He was at first for four years on the personal staff of Mr. Devonsher Scott, then Chief Resident of the Midland and North-Eastern Systems; but about the year 1876 he was sent to Alicedale as Assistant Engineer, under Mr. F. G. Slessor, and remained there until the completion, in 1879, of the works on which he was employed. Mr. Chittenden next joined his old chief, Mr. Kilgour, who was established at Kimberley as a Mining Engineer, becoming his partner; but, in 1882, the diamond-industry, which constituted all the real life of the Kimberley district, almost collapsed, and Mr. Chittenden returned, for a time, to his service under the Cape Government, rejoining Mr. Slessor, at first as Draughtsman, and then as First-class Assistant on the Lucan, Truro and Aliwal line. He remained here until his section was completed, in 1885. Shortly afterwards he entered the Victorian Government Railway Department, and remained in Australia until his death, on the 1st of March, 1890.

Mr. Chittenden was hard-working, and attentive to his duties. Personally, he was much liked, being of a most unselfish, kind-hearted and hospitable character; and his death, at the age of forty-four, was much regretted by his old comrades. He joined the Institution as an Associate Member on the 23rd of May, 1882.

WILLIAM HACKNEY, the only son of the late William Hackney, merchant, Dundee, was born at that place in 1841. He became a Graduate of the London University in 1857, and three years later he took an Exhibition, on which occasion he obtained honours in Biology. He was awarded the Duke of Cornwall's Exhibition from the Royal School of Mines in 1861–2, and received the first Certificate for Anatomy and Physiology, and the Gold Medal in 1861–2. In 1862 he took the degree of B. Sc., and also a Scholarship, and was made a Life Governor of the London University. After he left College, he was for some years in the office of Sir William Siemens, and became that gentleman's principal assistant. By him he was, in 1870, appointed Manager of the Siemens-Steel Works, at Landore, near Swansea, and entered upon his duties with the greatest energy and enthusiasm.

Mr. Hackney was the author of two Papers read before the Institution: "The Manufacture of Steel,"[1] for which he was awarded a Telford Medal and Premium; and "The Adoption of Standard Forms of Test-pieces for Bars and Plates,"[2] for which he obtained a Telford Premium.

Mr. Hackney was elected an Associate of the Institution on the 6th of April, 1869, and his early career gave every promise of a distinguished and brilliant position. But in 1875 he was attacked

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[1] Minutes of Proceedings Inst. C.E., vol. xlii. p. 2.

[2] *Ibid.*, vol. lxxvi. p. 70.

by a subtle malady, which obliged him to desist almost entirely from active work. Thence, until his death on the 4th of February, 1890, he was obliged to lead a life of seclusion.

EDWARD RAINFORD JACKSON, the son of a colonial judge, was born in Jamaica on the 28th of April, 1860. He came to England in 1879, and entered the Thames Ironworks on a three-years' term, under Mr. Richard Hodson. On the expiry of his articles, in August, 1872, he was for a short time with Mr. T. B. Lightfoot, and then went to the Crystal Palace School of Practical Engineering, to learn surveying and colonial work, with a view to an appointment under a Colonial Government. In the interval of obtaining what he wanted, he returned to Mr. Lightfoot, but, being shortly after incapacitated by an attack of congestion of the lungs, he resolved at once to leave England for a warmer climate. He went back to Jamaica, and succeeded in obtaining an appointment under the Superintendent of Roads and Work, being chiefly concerned with irrigation works, and retained his post until his sudden death on the 13th of July, 1889.

Mr. Jackson was elected an Associate Member of the Institution on the 4th of May, 1886.

DAVID WALLACE, eldest son of James Wallace, the Brake, St. Andrews, N.B., was born in New Zealand on the 18th of October, 1847. He was educated at the Madras College, St. Andrews, and at the University of that city. He was then articled to the late Mr. John Sang, of Kirkcaldy, under whom he served for more than a year. He was attracted by the terms offered by the Secretary of State for India to Engineers willing to enter the Indian Public Works Department, and, passing successfully the annual competitive examination for candidates, held in London in 1867, he joined the service on the 26th of July that year. He arrived in India on the 18th of October, 1867, and was posted as a third-grade Assistant Engineer to the Central Provinces. Immediately after joining he was appointed to the Kanhan Division, under Mr. F. L. O'Callaghan, C.S.I., C.I.E., now Consulting Engineer to the Government of India for State Railways. Under Mr. O'Callaghan he was engaged for some time on the construction of the Kanhan Bridge, a work of considerable magnitude, and the largest and most important undertaking of the kind then being carried out in the Central Provinces. The Chief Engineer of the Central Provinces at that time—the late Mr. T. W. Armstrong—spoke of Mr. Wallace in an official report as an intelligent and careful officer, successful in carrying out all works entrusted to him. Mr. J. G. H. Glass, now Superintending Engineer, Central Provinces, reported officially on the care and ability shown by Mr. Wallace on the Kanhan Bridge works, and the success he attained. In a subsequent report by the same officer, he is described as, "a careful and most practical Engineer, most zealous in the performance of his duties." Mr. Wallace passed through the usual departmental grades, and attained the rank of Executive Engineer, first grade, in May 1888. Professionally he was most careful and painstaking, and was possessed of a considerable knowledge of the details of construction, which enabled him to carry out the works entrusted to him in a very economical and efficient manner. In private life Mr. Wallace was quiet and unassuming, of a retiring disposition, and not given to ostentation. To those who knew him well he was a kind and genial friend, and his loss is greatly regretted by them. He died at sea, on board the s.s. "Bokhara," on the 5th of May, 1889, before reaching Aden on the homeward voyage.

Mr. Wallace was elected an Associate Member on the 2nd of December, 1873.

WILLIAM HENRY BARRY, son of Mr. Frederick Barry, and a nephew of the late Sir Charles Barry, the architect of the Houses of Parliament, was born in London on the 2nd of October, 1824, and was educated at the King's School, Canterbury. Here he distinguished himself by his ability and assiduity, and obtained several prizes. On quitting school, it was determined that he should follow the profession of a Civil Engineer, and with this view he entered the Applied Sciences Department at King's College, London, then recently opened, and known as the Engineering Department. He followed his studies there with the keenest interest, earning the marked approval and good-will of all the Professors, but perhaps particularly the late Professors of Mechanics and of Chemistry, Moseley and Daniell. At about this period an event occurred which compelled him most unwillingly to change his career; his father, a member of the Stock Exchange, died after a protracted illness, leaving a widow and family dependent upon the business, and the duty of carrying it on devolved upon the subject of this memoir. He was indeed successful in this career —as he would, doubtless, have been in any pursuit to which he addressed his energies and his abilities—but engineering remained the subject of his predilections; he abandoned it with the greatest reluctance, and would, in all human probability, have risen to high eminence in it had he been able to follow it as a vocation. As it was, he took an active interest in all works of engineering, and in the engineering features of those public enterprises which came before him in the course of his business. He was elected an Associate of the Institution on the 5th of April, 1859, and was for many years a most regular attendant at the meetings; he also accepted the duties of Auditor in the years 1876 and 1877.

Of Mr. Barry's character in social life it is difficult to speak too highly. Genial, active, zealous, honourable in the highest degree, and ever unselfish, he was not only the firm friend of those who formed his own circle, but the generous helper of the young, and of those who needed encouragement and assistance. As an evidence of the esteem in which Mr. Barry's abilities were held at King's College, it may be mentioned that, even after he had entered upon business, he was invited by the late Professor Moseley to collaborate with him on the publication of his "Principles of Engineering and Architecture."

Mr. Barry died on the 15th of January, 1890.

LIEUTENANT-COLONEL CLAYTON SCUDAMORE BEAUCHAMP was born on the 24th of April, 1842. At the age of nineteen he entered the Royal Engineers, and soon after was employed at the blowing up of the forts of Corfu, having charge of the experiments then tried with gun-cotton. In 1865 he joined the Indian Public Works Department, and was posted to the Gurruckpore District, N. W. P., as Assistant and District Engineer. It was a large, wild, and much-neglected tract of country bordering on Nepaul. Lieutenant Beauchamp was there for some years, and the roads, bridges, and public buildings benefited greatly by his care and attention. During the two latter years of his stay, extensive Famine Relief Works were started and had to be carried on, and he had to keep things straight, and to look after from thirty thousand to forty thousand people, men, women, and children, no slight responsibility for so young a man. His unwearied attention and judicious management of the business elicited the best thanks of the local Government. In 1870 he was made Assistant Principal of the Thomason Civil Engineering College at Roorkee. Two years later he was promoted, and posted as personal Assistant to the Chief Engineer, the duties of which position he fulfilled so satisfactorily that he was soon advanced, being made Captain, and appointed Under-Secretary to Government. This was a position of great trust and heavy responsibility, both from an engineering and financial point of view. He remained here until October 1880, coming to England in the early part of 1881. In December of the same year he was made Major; and in 1882 returned to India, being transferred temporarily to the Railway Board. Major Beauchamp had the pen of a ready writer, and contributed long articles to the "Pioneer;" so able and pungent were some of these contributions, that they brought him into conflict with his superior officers in a rather unpleasant manner. This led to his giving up his post as Under-Secretary to Government, and he was transferred temporarily to the Railway Branch. In September 1884, Major Beauchamp reverted to English service, and was stationed at Glasgow. In May 1885 he was transferred to Chatham, where he remained until his retirement from the Corps with the honorary rank of Lieutenant-Colonel. He died at Hastings, in March 1889.

Colonel Beauchamp was highly esteemed by his associates, being ever ready to help and give good advice to his fellow-officers of the Department. Socially he was in great request, being a most genial companion and valuable friend. He was elected an Associate of the Institution on the 2nd of May, 1876.

MAJOR FRANCIS GEORGE SHIRECLIFFE PARKER,[1] late H.M. 54th Regiment, was born in 1836. At the early age of seventeen he received his Commission in the 54th Regiment, and in a short time was appointed Musketry Instructor. In 1858 he proceeded with his regiment to India, and, though arriving when the worst of the Mutiny war was over, he saw some service, and received the Mutiny medal. Later on, he joined the Public Works Department, having first passed out of the Thomason Civil Engineering College, at Roorkee, with distinction, and as an

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[1] The substance of this notice is from *The Kingsman*, the organ of King's College, London, March 17, 1890.

engineer carried out several important works. After some few years he rejoined his regiment; but hard work and a trying climate had broken down his health, and, returning to England a complete invalid, he retired from the service in 1877.

With an honourable career to look back upon, he might well have elected to pass his later life in rest; but he was too much the soldier to wish to be idle; and, with health more or less restored, and possessed of private means, he entered himself as a student in the Theological Department of King's College, London, intending to take Holy Orders, with the sole view of gratuitously assisting clergy who might not be able to afford such assistance when ill, or requiring rest.

Well read, well informed, and a man who had himself exercised authority, he did not, when the good of others was concerned, shrink from again subordinating himself to college life, and, with duty as his watchword, he right loyally conformed to its every rule. He was always ready to join whatever was for the good of the College, and for this its walls will hold his memory kindly, while for those who had his friendship there remains the recollection of one who was courteous, kind, and sympathetic—who was at once a Christian, an officer, and a gentleman.

He died on the 28th of February, 1890, literally in harness, for he was leaving his house for College when seized with a sudden sickness which caused a blood-vessel of the brain to burst, and in a short half-hour all was over.

Major Parker's body was removed from his house at Kensington to Sturry, near Canterbury, where he had a small property, and laid to rest by the side of his wife in the churchyard of that place. Major Parker was elected an Associate of the Institution on the 4th of December, 1866.

THOMAS ANDREW WALKER was born in 1828. After a brief course of engineering instruction at King's College, London, he, at the age of seventeen, began his professional career on various surveys, executed in the feverish times of the railway mania. On the bursting of that bubble he had to abandon his intention of becoming a civil engineer, and was fortunate enough to obtain an appointment under Mr. Brassey, who was carrying out the contract for the North Staffordshire Railway. He remained in Mr. Brassey's employ until 1854, being engaged on the Royston and Hitchin, the Newcastle and Ashbourne, and, for the last two years of the time, on the Grand Trunk Railway of Canada. Mr. Walker then began contracting on his own account, and remained in Canada for a further period of seven years constructing railways for the Government of the Lower Provinces. He returned home in 1861, after an absence of nine years, and reverted to engineering, as an assistant of Mr. P. Pritchard Baly, for whom he made the survey of the Orel and Vitepsk Railway, in Russia. He next went to Egypt for Mr. Charles Manby, and during 1864 and 1865 made extensive railway surveys in that country and in the Soudan, where he reached as far as Metammeh, 100 miles north of Khartoum. On his return to England Mr. Walker was offered, and accepted, the management of the contracts for the extension of the Metropolitan Railway and the construction of the Metropolitan District Line. These works, among the heaviest in modern engineering, had been undertaken jointly by Messrs. Peto and Betts, Mr. Kelk, and Messrs. Waring Brothers. For the associated firms, Mr. Walker supervised the whole of the contracts from Edgware Road to the Mansion House, the works near the latter station being carried on day and night, in order to ensure their completion by the 1st of July, 1871. From this time until his death Mr. Walker was continuously engaged on his own account (at first in partnership with his brother, the late Mr. Charles Walker, and, since that gentleman's death, alone), in the execution of engineering contracts of the most important character. In this way he undertook the extension of the East London Railway, from the northern end of the Thames Tunnel to its junction with the Great Eastern line at Shoreditch. This part of the line is carried under the London Docks, and entailed very heavy works in the densely populated districts of Wapping, Shadwell, and Whitechapel. The Engineer-in-chief of this work was Sir John Hawkshaw, F.R.S., Past President Inst. C.E., and the connection thus initiated formed an important epoch in Mr. Walker's career. For Sir John Hawkshaw he appears to have entertained the profoundest admiration and respect, amounting almost to reverence, and this eminent engineer must have been thoroughly satisfied with the way in which Mr. Walker fulfilled his obligations; for, when the doubtful and difficult work of the Severn Tunnel had reached the final stage of preparation, Sir John chose Mr. Walker to carry out his designs. Mr. Walker regarded the Severn Tunnel as the most arduous undertaking in which he had been concerned. Of this work he wrote an account, the preface of which has been largely consulted in the preparation of this notice.[1] In it he says, "Subaqueous tunnels have recently become quite the fashion. One such experience as the Severn Tunnel, with its ever-varying and strangely contorted strata, and the dangers from floods above and floods below, has been sufficient for me. One sub-aqueous tunnel is quite enough for a lifetime."

Other great works of which Mr. Walker undertook the construction were the Barry Dock and Railways, the Preston Dock, the great Government Docks at Buenos Ayres, and, last but not least, the Manchester Ship Canal. It is, of course, too early to speak of results as regards this formidable work. It will suffice to say that Mr. Walker's lamented death will not, as far as can be foreseen, delay the execution of the contract, as he had made all the necessary arrangements for its completion, in the event of his death, by his executors and staff of agents. In popular estimation, the construction of the Manchester Ship Canal, probably, would have been considered Mr. Walker's *magnum opus*, although he appears to have been more proud of the Severn Tunnel. But the wonderful concentration of plant and labour on the Canal, and the energy and vigour with which the works are being carried on are better calculated to impress the non-professional mind than the more difficult and dangerous operations carried on beneath both land and water, and so out of sight. On the comparatively short length of 35 miles of the Manchester Ship Canal there are 221 miles of temporary railway, 90 excavating machines, 171 locomotives, and 6,296 wagons, the whole value of the plant being £850,000, while 14,000 men, are employed on the works, which are pushed forward day and night. For some time before his death Mr. Walker was carrying out, concurrently with the canal, docks at Barry, with 2,000 men, and at Buenos Ayres with 5,000 men, thus giving employment to an army of 20,000 men, in whose moral and material welfare he exhibited the greatest solicitude. At the opening of the Barry Docks, in the summer of 1889, it was noticed that Mr. Walker was absent from the entertainment given by the Railway Company, to celebrate the occasion, and he was found presiding at a dinner he had given to his 2,000 navvies, who he had determined should not be neglected on such a day.

The mental strain induced by the responsibilities attendant upon such gigantic enterprises no doubt tended to shorten Mr. Walker's life. He had returned from a visit of inspection to the

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[1] "The Severn Tunnel: its construction and difficulties. 1872–1887." By Thomas A. Walker. 8vo. London, 1888.

Buenos Ayres Harbour Works when the first symptoms of serious illness manifested themselves, and he gradually got worse, until his death, from Bright's disease, on the 25th of November, 1889, in his sixty-second year. He was elected an Associate of the Institution on the 2nd of April, 1867.

Mr. Walker was well worthy of a place in the front rank of English contractors, his works vying with the best of those carried out in the heyday of railway construction. In one respect his enterprises were unique. They did not consist of long stretches of railway, in which, the preliminary organization once perfected, the construction could be expected to go on with clockwork precision, under the supervision of clever and intelligent subordinates, but were generally undertakings of moderate extent but of the most costly and elaborate character, carried out under conditions which necessitated the solution of nearly every problem known to the engineer. Thus the Manchester Ship Canal, for its whole length, resembles the construction of one continuous dock, with all the formidable and delicate works attending the diversion of roads, railways, and canals crossing the line of route in every direction. For this sort of work Mr. Walker was, by his early engineering training, peculiarly fitted; and his comparatively early death is a distinct loss, not only to his own friends, but to the country, in the prosecution of whose public works he took such an important part.

MAJOR THEODOSIUS WEBB, late Royal Engineers, was the second son of Sir John Webb, C.B., K.C.H., Director-General of the Ordnance Medical Department. He was born at Woolwich on the 28th November, 1817, and died at his residence, Elmwood, St. Peter's, Isle of Thanet, on the 17th December, 1889.

Theodosius Webb entered the Royal Military Academy at Woolwich, on the 7th February, 1832, where he obtained a prize for distinguished proficiency in Mathematics, and was appointed 2nd Lieutenant in the Corps of Royal Engineers on the 4th January, 1836. He was promoted to 1st Lieutenant 27th October, 1837, and 2nd Captain 30th January, 1847. During this period he served at Chatham and Woolwich, where he was, for some time, Adjutant of the R.E. quartered in that garrison, and also at Gibraltar, from which station he was invalided, having suffered severely from sunstroke; but subsequently returned there to complete his tour of service.

In June, 1847, Captain Webb received orders to proceed to Zetland, for the purpose of surveying a line of road to be undertaken by the Local Committee, under the Edinburgh Section of the Central Board for the relief of destitution in the Highlands and Islands of Scotland.

Arriving in Zetland on the 31st July, 1847, he at once commenced Surveying operations; but after two months of hard work was obliged to abandon them, the season being unusually severe and the fatigue and exposure great. He was, at the beginning of October, 1847, sent to Gairloch, in Wester Ross, where he was employed, for nearly two months, in the most inclement weather which had been known for years, in surveying a line of road from Kinloch Ewe to Slatterdale and Poolewe. After completing this survey, he returned to Woolwich, where he was engaged, during the winter, in making plans, &c., for the Wester Ross Road.

In May, 1848, he went back to Zetland and remained there until the 1st September of that year, having, during that period, surveyed upwards of seventy miles of road. The climate of Zetland, and the difficulty of travelling rendered this service very laborious. In the following spring it was proposed to commence road-making; and Captain Webb arrived again in Zetland on the 11th April, 1849; but that month being very boisterous, and heavy snowfalls occurring, little or nothing could be done till near the beginning of May, from which time, up to February 1851, he was actively employed in the supervision of the works; and on leaving the Islands he had (to quote the words of the report of the Inspecting Officer of the Committee) "the satisfaction to see upwards of 40 miles of road available, and beginning to be appreciated in the country; and also the gratifying reflection, that to his unwearied zeal, tact, and talent are the Zetlanders mainly indebted for a most important improvement in their social position." On his departure from Zetland he was presented, by the numerous friends whom he had made during his residence there, with a silver salver, and tea and coffee service, "as a sincere though inadequate, expression of their esteem for his private worth, of their sense of his professional talent, and of their gratitude for the manner in which he combined a warm and disinterested zeal for the social improvements of the Islands with an energetic and impartial discharge of his public duties." After this trying and arduous service in a cold, inhospitable climate, Captain Webb was ordered to embark immediately for Hong Kong; but, having never thoroughly overcome the effects of his illness at Gibraltar, it was considered that service in China would be seriously prejudicial to his health, and he was compelled to retire on half-pay in 1851. In 1853 he was appointed Captain in the Kent Militia Artillery, with which regiment he served whilst it was embodied during the Crimean War. He for a short time held the post of Assistant Secretary to the Executive and Finance Committee of the Royal Commission of the Patriotic Fund, which he resigned on the embodiment of the Militia, receiving, from Lord St. Leonards, the Chairman of the Committee, their thanks for the able and assiduous manner in which he had performed his duties, which included the operation of receiving and entering a sum of £227,204 in the short period of three months and half. On the disbanding of his Militia Corps, he accepted the Secretaryship of the Small Arms Committee, which he held until its abolition. In 1858 he finally retired from the army with the rank of Major, and settled down into private life at Elmwood, where he occupied himself in making and recording meteorological observations, in which he was greatly interested, and with other scientific pursuits.

He was a J.P. for the county of Kent, but never took his seat on the Bench; a most active member of the Committee of the Margate Sea Bathing Infirmary, from whose meetings he was rarely absent, and latterly Secretary of the Kingsgate Branch of the National Life-boat Association. But to a man of his active mind, great abilities, and devotion to the Service, from which he was obliged to retire prematurely, these occupations were a poor substitute for those larger interests of the profession, in which a distinguished career appeared, at one time, to be assured to him, and his forced abandonment of which was a never-ceasing source of regret—not only to himself, but to all with whom he was connected.

A man of fine physique, and commanding presence, his eminently social qualities made him popular in his Corps, and amongst all with whom he came in contact, both in public and private life.

Major Webb was elected an Associate of the Institution on the 13th of January, 1852.

⁂ The following deaths have been made known since the 31st of March:—

Members.

Abbott, Samuel; *died* 17 May, 1890, *aged* 48. (*Typhoid fever.*)

Buchholz, John Augustus Arnold; *born* 12 October, 1846; *died* 13 May, 1890.

Carrick, John; *born* 6 May, 1819; *died* 2 May, 1890. (*Influenza.*)

Inglis, William; *born* 10 May, 1835; *died* 22 April, 1890. (*Pneumonia.*)

Mackintosh, Alexander; *born* 8 July, 1820; *died* 23 March, 1890.

Stephenson, Henry Palfrey; *born* 27 March 1826; *died* 30 April, 1890.

Swallow, James Stuart; *born* 14 December, 1849; *died* 6 April, 1890. (*Exposure.*)

Associate Member.

Hall, William Jeremiah, B.E.; *born* 17 July, 1853; *died* May, 1890.

Information respecting the life and works of any of the above is solicited in aid of the preparation of future Obituary Notices.—Sec. Inst. C.E., 3 *June*, 1890.

SECT. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

On the Nature of Brittle Bodies, and the Numerical Expression of Hardness. By Dr. FRIEDRICH KICK.

(Technische Blätter, 1889, p. 165.)

Brittle bodies are those which become plastic when exposed to a high pressure exerted equally on all sides. Hardness can be expressed numerically (when bending and flow of particles is prevented) by the resistance to shearing.

The following experiments will establish the truth of these two statements. Let the brittle body be enclosed in a somewhat harder but equally brittle substance, and let these two be again enclosed in a harder but plastic body, it will be found that, by bending or altering the outer shell, the form of the enclosed brittle body will be similarly altered. The brittle bodies experimented upon were gypsum, rock-salt, calcite, &c. These were placed inside a piece of gas-pipe and surrounded with melted shellac, one end of the tube being closed with a well-fitted plug, and great care being taken to exclude the air, and the open end of the tube then closed with another plug. After thorough cooling the pipe was bent, and then dissolved off with dilute nitric acid, and, the shellac being dissolved with spirit, the piece of gypsum was found to be bent without any signs of cracking. The experiment may be tried in a different form, the brittle body can be enclosed in a thick copper ring, soldered to a plate, and filled up with shellac melted at 212° Fahrenheit, when cold, if the ring be squeezed in an hydraulic press into a barrel-shaped form, and the shellac being dissolved out with spirit, the brittle body will be found altered in form similarly to the copper ring. The Author has by this means altered the shape of natural crystals of rock-salt as if they were plastic.

A square block of rock-salt placed on one angle can be pressed into a rhomb, and the angles of an hexagonal piece can be pressed in, so as to cause the flat sides to bulge out. Sulphur may be used as the surrounding medium in place of shellac. A fusible metal composed of bismuth 50 parts, lead 30 parts, antimony 20 parts, and tin 5 parts, although of nearly the same hardness, has not answered so well, it being difficult to make the fused metal completely fill up the cavity round the piece. It is noticeable that sulphur is somewhat softer than calcareous spar; this fact led the Author to try a very easily fusible substance, stearine, and one that is very liquid when melted, and numerous experiments with rock-salt proved that stearine was equally effective as shellac and much more convenient to use. The surrounding medium must not be much harder than the enclosed piece, and from this it naturally follows that it is due to the high pressure exerted equally on all sides that the brittle body behaves as if plastic.

After these successful experiments the Author tried the effect of fluid pressure. The apparatus consisted of a piece of soft copper with a hole accurately bored not quite through, so as to leave a thickness at the bottom. The piece to be experimented with was placed at the bottom of the hole, which was then filled up with oil; a steel plunger of slightly larger diameter than the hole was inserted, and then forced down in a press, a small hole drilled laterally near the top of the copper block allowed air to escape, and as the steel plunger was forced down the piece of calcite was subjected to fluid pressure, before the plunger reached it, and also during the time of actual pressure by contact of the plunger; the piece of calcite, &c., originally 8·1 millimetres ($\frac{5}{16}$ inch) high was reduced to 5·3 millimetres ($\frac{13}{64}$ inch) without any crack appearing, but the transparency was somewhat impaired. The harder and more brittle the material the greater the pressure required to alter the form of the piece.

The Author remarks that it may be said that these experiments are too limited to establish the definition of brittle bodies as given at the beginning of the Paper; but he further remarks that the substances he experimented with, such as talc, gypsum, rock-salt, shellac, sulphur, stearine, and calcite, are very dissimilar in their nature, and that each of them in turn can be altered in form as if plastic by a suitable surrounding medium, and by the application of pressure when so surrounded.

Passing on to the second question, How can hardness be expressed numerically? the Author by experiment has been enabled to show that hardness may be expressed in terms of the resistance a body offers to shearing, but in making these experiments the piece to be sheared must be so held as to prevent any flow of the particles. The Author found that at ordinary temperatures two very dissimilar substances, tin and shellac, showed the same resistance to shearing, and the same hardness when tried by other means. He also experimented with other substances, and remarks that the subject requires an exhaustive series of experiments to thoroughly establish the proposed definition, that hardness is proportional to shearing resistance. The Paper is illustrated by figures explaining the apparatus used.

H. H. P. P.

Instrument for Measuring the Elastic Properties of Materials.

By — Phillips.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cix. 1889, p. 687.)

The instrument is similar to the balance wheel and spiral spring of a chronometer, but made on a much larger scale. The metal, of which the elastic properties are to be investigated, is drawn into a wire of about 1 millimetre (0·039 inch) diameter, and a spiral is made from it and suitably attached to the balance wheel. The modulus of elasticity can now be determined in two ways, either by observing the time of oscillation or by the direct measurement of the torque required to produce a given deflection. The Author gives the following equations for these two cases:

$$(1) \quad . \quad . \quad T = \sqrt{\frac{A\,L}{E\,I}} \qquad\qquad (2) \quad . \quad . \quad G = \frac{E\,I\,a}{L},$$

where T, in the first equation, is the time of one simple oscillation, A the moment of inertia of the balance wheel, L the length of the spiral, I the moment of inertia of its cross section, and E the modulus of elasticity; G, in the second equation, is the torque required to produce the deflection a. The rate of extension i of a spiral made of circular wire of diameter d is given by the formula $i = \frac{d\,a}{2\,L}$, and by selecting the angle of deflection so large as to produce a permanent set, which can be seen by the balance wheel not returning to its original position, the instrument can be used to determine the elastic limit.

G. K.

Frost-resisting Cement Mortars. By — Bernhofer.

(Wochenschrift des österreichischen Ingenieur- und Architekten-Vereines, 1890, p. 16.)

It being well known that Portland cement mixed with strong hydrochloric acid or with a saturated solution of soda, sets at once and becomes extremely hard, the Author carried out the following experiments with mortars composed respectively of Portland cement and sand, and lime and sand, each mixed with a solution of crystallized soda (the temperature of the air being 22½° below zero, Fahrenheit) in order to observe the influence of frost on their quick-setting properties.

The exact composition of the mortars was 1 litre (1·76 pint) of Portland cement, and 1 litre of lime, each mixed with 3 litres of river sand, and a solution formed of 1 kilogram (2·2 lbs.) of crystallized soda and 2 litres of water.

The experiments commenced at 7.30 P.M. on December 9, 1889, and continued till 10 A.M. on December 10th, a period of fourteen hours and a half. During the night the temperature fell to 31½° below zero; at 8 A.M. on the 10th December it was 24¾°, and at 10 A.M. 15¾° below zero, when the mortars were taken into a room and put into a hot oven for three hours. At the expiration of this time it was found that the extreme cold had had no disadvantageous effect on their setting qualities: there could therefore be no doubt that mortars prepared from Portland cement and lime with a solution of soda would withstand the injurious effects of frost. The Author therefore proposes further experiments to ascertain whether these mortars retain their hardness for a long period, and whether the larger quantity of soda used is absolutely necessary, as the cost of the mortar is mainly dependent on the amount of soda employed.

The cost of these frost-resisting mortars, composed as above stated, is given as follows:—

	£	s.	d.
1 cubic yard Portland cement mortar	3	0	0
1 „ „ lime „	1	5	6

W. H. E.

Destruction of Large Masses of Iron or Steel by Blasting.

By HUGO MÜNCH.

(Wochenschrift des österreichischen Ingenieur- und Architekten-Vereines, 1890, p. 59.)

The Author classes these under three heads, viz.: 1. Bodies which can be broken, or rather blown to pieces, by charges of dynamite laid loosely on or against them. 2. Hollow bodies, where the blasting-charge can be placed as in a bore-hole, or whose capacity is sufficiently large to admit of their being filled with water, into which the dynamite charge can be placed. 3. Huge masses of steel or iron which must be bored into as if they were rock and then blasted.

Under the first head is included mainly the destruction of iron railway bridges in time of war, and which the Civil Engineer therefore seldom has an opportunity to deal with. The Author, however, quotes the iron bridge (on the Leipzig-Dresden line of railway) over the Elbe at Riesa which, destroyed by a flood in 1870, fell into the river below, completely blocking the bed, and had to be blasted out.

Under the second head are comprised large guns, press-cylinders, boilers, &c.; and, under the third head, rolled steel and iron plates, and rails, cofferdam piles, blast-furnaces, &c.

The formula adopted by the Corps of Military Engineers, for bodies classified under the first head, is $L = 0 \cdot 0063bd^2$,

where L = dynamite charge in kilograms.
b = breadth of body in centimetres.
d = thickness „ „

and this formula applies to wrought-iron structures solid or riveted, provided the rivets are more than 16 centimetres apart; but wrought-iron plates with rivets less than 16 centimetres apart, and all cast-iron plates require only half the charge given by the formula; cast-steel plates, however, require double this charge. Examples are given of the application of the formula to the case of an iron chain-link, and two girders of different section. Under No. 2 head it is stated that the charge for guns, or other similar bodies filled with water, would be 0·1 kilogram of dynamite per centimetre of diameter; for example, for a gun 16 centimetres in diameter, the dynamite charge would be 1·6 kilogram. The following particulars are given of the blasting of a 21-centimetre breech-loading bronze gun. The tube was 4·425 metres (14·5 feet) in length,

diameter of bore in the rifled part = 20·9 centimetres (8·25 inches),
thickness of metal at the breech = 31·3 „ (12 „).

The total weight was 14,169 kilograms (31,171 lbs.), and the breech-chamber was lined with a copper tube 94·8 centimetres (37·323 inches) long and 6·6 millimetres (0·25 inch) thick.

The Committee which conducted the experiment filled the gun with water, and then exploded a charge of 6 kilograms (13·2 lbs.) of dynamite in it. This did little damage, so the water was poured out, and a second charge of 36 kilograms exploded; this only bulged and cracked the tube but did not burst it. A third charge of 94·5 kilograms of dynamite shattered the gun into thirty-four large and forty smaller pieces, of which the largest weighed 1,850 kilograms, and four other pieces 1,500 kilograms each. The Committee's referee gave it as his opinion that the charge of 94·5 kilograms was the proper charge to have used at first, the gun having been previously filled with water. Other examples are given of the success of the Author's experiments in the Archduke Albrecht's works at Trzynietz, in destroying with dynamite a large press-cylinder and two boilers, the charge in each case being less than half that given by the formula above for guns, the reduction being due to the trifling thickness of the metal in comparison with the diameters of the cylinder and boiler. Under the third head, the Author confirms the opinion of Engineer Trauzel, Director General of the Nobel Dynamite Works, viz.: That bore-holes from 21 to 30 millimetres in diameter and repeated small charges are the only rational methods of blasting very large masses of iron or steel; and he has found that 1,000 kilograms of these metals can be blasted into pieces sufficiently small for re-casting at a cost of about 2½ florins.

The Paper is illustrated by diagrams and sections of the various bodies experimented on.

W. H. E.

On the Resistance of Ropes to Bending Stress.

By L. de Longraire.

(Mémoires de la Société des Ingénieurs Civils, October 1889, p. 460.)

The resistance of ropes to bending stress (*raideur*), in passing over a pulley or a barrel, has usually been comprised in one valuation with other passive resistances of ropes and cords of hemp or of metal. But the experiments of Mr. Murgue, made in 1887, have supplied data which previously had been almost entirely wanting. The Author epitomizes, historically, the investigations of authors, French, English, and German; with a critical examination of the various existing theories, all of which he rejects.

The Author calls attention to the internal wear of hemp-ropes which are much used. They are reduced internally to a sort of powder. In the case of the captive balloon at the Exhibition of 1878, the rope which was wound on a roller of very large diameter and passed over a pulley, 1 metre in diameter, on its way to the car, stretched excessively, and the inner portion proved to have been reduced to powder—the result of the friction of the strands on each other. A new rope having the core well greased was substituted, and the phenomenon of internal wear ceased. In wire-ropes, on the contrary, the wear of the interior wires is very little—they polish each other.

The Author cites an empirical rule, for certain coefficients of safety, bearing upon the relative strength of iron wire-ropes and hemp-ropes: that these ropes may be loaded with one thousand times their weight per lineal metre.

Formulas based on the results of experiment are given for the stiffness or resistance to bending of hemp-ropes, iron wire-ropes, and steel-ropes, as follows:—

——	French Formulas.	Equivalent English Formulas.
Hemp	$S = 0{\cdot}04\,T\,\frac{p}{D}$ . . .	$S = 0{\cdot}0328\,T\,\frac{p}{D}$ . . .
Iron wire-rope . . .	$S = (2{\cdot}00 + 0{\cdot}0032\,T)\,\frac{p}{D}$	$S = 3{\cdot}61 + 0{\cdot}00262\,T\frac{p}{D}$
Steel wire-rope . .	$S = (3{\cdot}50 + 0{\cdot}0032\,T)\,\frac{p}{D}$	$S = 6{\cdot}314 + 0{\cdot}00262\,T\frac{p}{D}$
Do. rusty	$S = (3{\cdot}00 + 0{\cdot}0032\,T)\,\frac{p}{D}$	$S = 5{\cdot}412 + 0{\cdot}00262\,T\frac{p}{D}$
Do. lubricated by immersion in an oil bath	$S = (1{\cdot}90 + 0{\cdot}0021\,T)\,\frac{p}{D}$	$S = 3{\cdot}428 + 0{\cdot}00172\,T\frac{p}{D}$

S = the resistance of bending (*raideur*) in kilograms; D = the diameter of pulley or barrel, in metres; p = the weight of the rope in kilograms per lineal metre; T = the tensional resistance in the rope at the approaching side, in kilograms. The English measures are in pounds and feet.

D. K. C.

Construction of Iron Roof for the Finland State Archives Office at Helsingfors.

(Zeitschrift des Vereines deutscher Ingenieure, 1890, p. 15.)

The excessive range of temperature in Finland—over 140° Fahr.—has of necessity a very great effect upon the stability of all iron structures erected in that climate, notably in bearings, connections, and in juxtaposition with other materials, improper provision for the variations of structural form being sufficient to endanger the safety of walls or abutments. In this connection, the construction of the iron roof over the great hall of the new Public Record Office (State Archives) at Helsingfors presents some original and noteworthy features. The hall measures 72 feet 5 inches by 43 feet 1½ inch. The principals, which are of ordinary construction, 8 feet 2½ inches in depth at the centre, with depressed tie, are carried on roller-bearings at each end, to admit of free elongation and contraction of the exposed roof-surface, trusses, and rafters. The ceiling, which is framed in iron, is at a level of 2 feet 6 inches below this tie-rod, and its rigidity and protection from the excessive variations of the external temperature are secured by the extension of the king and queen rods to a parallel tie below, built into the wall at each end, the intervening space being filled in with brick vaulting.

P. W. B.

A New Idea in Sheet-Piling.

(Engineering News, New York, March 1, 1890, p. 199.)

Mr. J. A. Wakefield, of Chicago, has introduced the following description of sheet-piling. Two 3-inch by 12-inch oak planks are taken as they come from the mill, and between these, lapping over half the width, is inserted another 3 by 12 oak plank. In piles from 20 to 25 feet long, these three planks are bolted together at the top, and the bottom by three ½-inch carriage bolts, and two more bolts would be put in about midway. In addition to these, four 6-inch boat-spikes are driven at intermediate points in each side of the pile. For light work the piles are dressed when in contact. The result is a pile 9 inches thick and 12 inches wide on the face, that can be driven with a monkey weighing from 2,800 to 3,000 lbs., and insure a strong, tight joint. As one side of the toe is bevelled, there is no difficulty in hugging the adjoining pile, and experience has shown that this form of pile will stand the pounding of an ordinary pile-driver without splitting off at the top.

This piling has been successfully used by Captain William L. Marshall, United States Engineer, at the La Grange lock, on the Illinois river, in a dam 820 feet long. During the progress of this work both dredges broke down, which prevented the proper backing of earth, and the successful closing of the dam was made possible by the excellent qualities of the Wakefield piling, which under a 7-foot head exhibited no leaks. Mr. Wakefield has obtained a patent for his invention.

F. G. D.

Compressed-Air Pier-Foundations for the New Harbour of La Pallice at La Rochelle.

By Messrs. THURNINGER and COUSTOLLE.

(Annales des Ponts et Chaussées, November, 1889, p. 455.)

The employment of caissons that can be removed and used successively for different parts of a foundation is, in some cases, the most economical system, and avoids the necessity of incorporating any iron in the structure, as must be done with the fixed caisson. The Authors give a very full and detailed account of an important instance of this kind.

The new works comprise a wet dock of 28½ acres, with a depth of 13 feet below datum level (or low water of equinoctial spring-tides), having quays of a total length of 5,905 feet, and with two dry docks, a lock 72 feet in width and 541 feet in length, a tidal basin of 29½ acres protected by two masonry piers having an opening between their heads 295 feet wide. The lock and basin are 3 feet 3 inches deeper than the wet dock. Neap-tides rise 15 feet 5 inches above datum, and mean spring-tides 19 feet. The entrance is from the roadstead of La Pallice, an anchorage sheltered by the islands of Ré and Oléron. As far as low water of spring-tides the work was of an ordinary character. A masonry cofferdam was built, by tide-work, uniting the two piers and the enclosed area dried. Beyond the cofferdam there was 1,037 lineal feet of the south pier to be built, running out to a depth of 16 feet 6 inches below datum, and 354 lineal feet of the north pier reaching a depth of 8 feet 3 inches. There were also 175,000 cubic yards of rock to be excavated over the area of the basin. It was for this portion of the work that caissons were adopted, and the interest attached to it arises principally from the exposed nature of the site.

The blocks built by means of the caisson were 65 to 69 feet in length and 26 feet 3 inches in width, of Portland cement masonry. They terminated 5 feet above datum, which is about mean low-water, at which level they were united by arches of 10 feet span. Above this a continuous wall was built 23 feet wide at its base, rising 9 feet 9 inches above highest spring-tides. The original intention was to use the caisson for all the rock excavation in the basin, but this was abandoned. The openings in the piers were closed by small iron caissons and filled in with masonry. A masonry cofferdam was built between the pier-heads, thus closing the tidal basin and allowing the excavation to be done in the dry. Full details are given in the Paper of the small caissons by which the spaces between the blocks were filled. The movable caisson was 72 feet 3 inches in length, 32 feet 10 inches in width, and 12 feet 6 inches in height. It was divided by a horizontal floor into two chambers, the lower being the working chamber open at the bottom, and the upper or balancing chamber being completely closed, so that by pumping it dry the caisson could be floated, and by admitting water to it the caisson could be sunk. There was also portable kentledge ballast in the balancing chamber and permanent ballast of concrete. There were four shafts with air-locks, two furnished with hoists operated by compressed air used for raising spoil and lowering stone, and the other two used by the workmen and also used (by means of small special air-locks) for mortar. Full details of the construction and calculations of the stability of the caisson are given. The method of raising the caisson as the masonry advanced was by means of twenty-four screw-jacks. The screws were of gun-metal 4¾ inches in diameter at the bottom of the thread. They bore upon the masonry through a cast-iron base-plate and on the caisson through a conical forging. They were turned by levers 6 feet 6 inches long, and relieved when the operation was complete by wooden chocks. A Table is given showing for each block the time consumed over each operation that had to be performed and the time lost. The number of days on which work was impossible, by reason of a rough sea, was about 23 per cent. of the whole period, which percentage would have been much smaller if work had been suspended during the winter months, and which was also increased by two causes that need not arise in similar work elsewhere. First, the caisson drew so much water that it could only be floated and passed over a finished block at spring tides, and then only in very calm weather. Secondly, the level of the water inside the caisson constantly varied with the rise and fall of waves outside, and when the weather was not too rough for work in other respects, work had to be stopped because of the water washing over the mortar at intervals. This was partially got over by building a wall round the edges of a block and supporting the caisson on that while work was done in the interior. The contractors were paid 42*s.* 9*d.* per cubic yard for all masonry in the piers up to 5 feet above datum. This price applied to 16,650 cubic yards of masonry built by compressed air and 2,850 cubic yards built in the open. The price covers plant and materials of all kinds except Portland cement. The excavation was paid at the rate of 7*s.* 10*d.* per cubic yard. This price applied to 5,540 cubic yards of rock in the foundations of blocks, excavated under compressed air, 155,400 cubic yards of rock excavated in the dry after closing the basin, and 15,050 cubic yards to be excavated under water outside the cofferdam. The price covers all plant and materials except lime and cement in the cofferdam, and except pumping, and includes the construction of the cofferdam.

The total cost of the two piers so far as built by compressed air, up to the level of 5 feet above datum, was £42 15*s.* per lineal foot (or, if the pier-heads be not included, £39). A comparison is made with the Boulogne pier on a rubble mound foundation, which has only cost between the same levels, £19 7*s.* per lineal foot, and it is said that the materials for such a foundation were not available here. At the Port of Sables d'Olonne, a pier on a rocky bottom, founded by means of concrete blocks built on shore and lowered to their place, cost £48 per lineal foot.

The Paper is accompanied by five plates, giving very full information on all parts of the subject.

C. F. F.

On Tests of the Ironwork of the Kieff Bridge.

(Stahl und Eisen, 1889, p. 917.)

In the summer of 1888 Professor Belelubsky was commissioned by the Russian Public Works department to examine and report upon the condition of the Kieff suspension bridge, then about forty years old, and particularly to examine the quality of the wrought-iron used in its construction. Fortunately a certain number of spare links, which are 12 inches broad, 1 inch thick, and about 12 feet long, had been preserved in the storehouse adjoining the bridge, so that it was possible to replace one of the original links by a new one, and to compare it with another unused one. Four test-pieces 1 inch by 1⅛ inch and 8 inches long were taken out of each link in the direction of the length, and one 4-inch piece transversely. The results were as follows:—

——	Tensile Strength.	Elastic Limit.	Elongation.	Contraction.
	Tons.	Tons per Square Inch.	Per cent.	Per cent.
Link taken out of bridge—				
Mean of four longitudinal tests .	21·8	11·1	14·05	17·35
One transverse test	14·9	..	2·1	1·6
New link from store-house—				
Mean of four longitudinal tests .	22·2	11·93	13·42	18·75
One transverse test	17·32	..	6·0	6·8

The longitudinal tests show that the strength of the metal is substantially unchanged, in which respect they confirm the previous observations made by Professor Bauschinger, at Munich, upon the iron of old bridges. The Author recommends that in all new bridges provision should be made for comparative tests of the strength of the metal at long intervals by preserving some spare bars from the original construction.

H. B.

Experiments on the Wire Rope of the Superga Railway.

By A. Galassini.

(Il Politecnico, 1890, p. 47.)

In wire-rope traction the rope itself is naturally the most delicate and most important part, requiring to possess the minimum of weight, great strength, ductility, hardness, flexibility and homogeneity, a high limit of elasticity, and perfect manufacture. The line up to the Superga, at Turin, is worked by a rope composed of six plies of eight steel wires each, or forty-eight wires in all. The diameter of each wire is 0·078 inch, of each ply 0·315 inch, and of the whole rope 0·985 inch; the weight being 1 lb. per lineal foot. The subjoined tables show the results of some tests of a 6 feet 6 inches length cut from this rope.

I. Breaking-Weight of the Single Wires of One Ply.

Wire Number.	Total Load.	Equivalent Load Reduced to Tons per Square Inch.	Notes.
	lbs.		
1	1,032	94·90	Broke at 4·3 inches from top.
2	1,014	93·22	,, 17·8 ,, bottom.
3	1,058	97·15	,, bottom.
4	1,023	94·04	,, 25·6 inches from bottom.
5	1,000	91·88	,, 20·5 ,, top.
6	908	83·48	,, 18·0 ,, bottom.
7	1,046	96·14	,, 12·0 ,, ,,
8	1,060	97·41	,, 4·0 ,, top.

Wire No. 6 appears to have been in some way injured. Taking this, however, as the average, the total breaking-weight of the rope (net sectional area = 0·225 square inch) would be 19·3 tons.

II. Breaking-Weight of remaining Five Plies.

——	Total Load.	Equivalent Load Reduced to Tons per Square Inch.
	lbs.	
Ply No. 2	7,931	91·08
,, 3	8,076	92·77
,, 4	8,527	97·92
,, 5	8,296	95·31
,, 6	8,807	101·15

III. Elongation of One Wire under Increasing Loads.
(Reduced to initial length = 1,000.)

Load in lbs.	Elongation.		
	Temporary.	Permanent.	Total.
220	1·55	..	1·55
264	1·86	..	1·86
308	2·18	0·01	2·19
352	2·49	0·02	2·51
396	2·83	0·04	2·87
440	3·13	0·09	3·22
528	3·83	0·16	3·99
616	4·52	0·40	4·92
704	5·25	0·75	6·00
792	5·95	1·25	7·20
880	6·59	2·01	8·60
968	7·38	3·65	11·03
1,003		Breaking-point.	

P. W. B.

The Bürgenstock Wire-Rope Railway. By A. Sommerguth.

(Zeitschrift des Vereines deutscher Ingenieure, 1890, p. 61.)

This mountain line, constructed to give access from the steamboat station Kehrsiten, on the Lake of Lucerne, to the summit of the Bürgenstock, has been opened after long difficulties in obtaining the necessary authority for construction, which was granted only after the favourable report of an international commission, and then only on condition that the carriages should work only from each end to the half-way passing-place and back. This restriction has since been waived, so that the carriages can run right through. It was originally intended to work the descending carriage by water-weight, but owing partly to the expense of getting the necessary quantity of water to the summit, and partly to the extra load, and therefore wear and tear of the ropes, this was abandoned; and the line is actually worked by electricity, the dynamos being set in motion by turbines on a stream about 2½ miles distant.

For the first length of 1,312 feet from the steamboat pier the incline is 32 in 100, the remainder rising at 57·7 in 100, giving an average throughout of 53·2 in 100, or 1 in 1·88. The horizontal length of the line is 2,713 feet, and the equivalent incline length 3,071 feet, the rise in this length being 1,444 feet. With the exception of a passing-place 394 feet in length, located on a curve of 558 feet radius, and at the change of gradients, the line is single throughout, and is constructed to the metre gauge (39·37 inches). The rails are laid with lead plate bed on 4 inches by $3\frac{1}{8}$ inches angle bar sleepers firmly secured in cement masonry. The traction is effected by steel wire rope 1·18 inch in diameter, composed of 114 wires tested to a load of eighty-nine tons per square inch, and weighing altogether 2·14 lbs. per lineal foot.

The line is laid, however, with a double-plate Abt rack rail, for gearing on the safety brake, by which the speed can be regulated, or stoppage effected in case of accident. These rack-plates are firmly fixed to the sleepers by stout angle-bars, with a clear intermediate space of 1·1 inch. The tee-section space thus obtained is utilised for anchoring down the carriage framing by a rod with head running in the groove, so that the vehicle cannot possibly be lifted off the rails. The outside wheels are grooved or double-flanged, and the inside wheels (*i.e.* those requiring to pass over the fixed points at the passing-place) are of plain cylindrical form, so that, the outside wheel being guided by the continuous rail, the inner wheel has no difficulty in passing over the rack and the rope grooves at the points.

The carriage consists of four compartments on an iron frame, the outside dimensions being 19 feet 8 inches by 5 feet 3 inches. There are two axles 9 feet 10 inches apart. The general brake-arrangements resemble those on the Pilatus railway. The carriage weighs 8,800 lbs., and accommodates thirty persons, the total load being therefore about 13,200 lbs., and the maximum tangential force 6,600 lbs. Adding the weight of the rope and the friction in hauling and winding, the total strain is equal to 13·46 tons, which gives nearly seven as the factor of safety. The vertical cast-iron grooved rollers for the rope are $6\frac{1}{4}$ inches in diameter, spaced at intervals of 49 feet; the diameter on curves, where the rollers are set in angular bearings, being 24 inches. The average speed is 197 feet per minute, or 2·236 miles per hour, giving therefore a little over fifteen minutes for the entire journey.

The water-power is derived from the Aa, between the villages of Stanz and Buochs, at a point about 1,400 feet below the level of the summit station. The volume of water is nearly 40,000 gallons per minute, with a fall of 16 feet 6 inches; and taking the effective work at 75 per cent., the power developed is equivalent to 150 HP. The turbines make on an average 49·5 revolutions per minute, the vertical shafts being geared by bevel wheels on to a horizontal shaft, making 145 revolutions and working two Thury's dynamos at 800 revolutions. The effective power developed is 88·8 per cent., and the current is transmitted by the triplex system to the summit station on the Bürgenstock, where the electrical energy is re-converted into mechanical work. The total weight of copper wire is 3,750 lbs., whereas the weight required for duplex transmission would have been about 10,000 lbs. The electro-motors at the Bürgenstock station make 700 revolutions a minute, giving 170 revolutions to the main driving-shaft and 5 revolutions to the 13-feet diameter winding rollers. The dynamos are also used for the electric-light installation, which comprises 225 glow-lights and one 2,000-candle arc-light. The stations and the turbine-house are also connected by telephone, and the carriages in approaching each end of the line cause a bell to sound in the engine-room, while the exact position of each car is reproduced diagramatically in the engine-room by indicators moving in the proportion of 1 to 1,000 of the travel of the rope. When not employed for working the line or the light installation, the electro-motors are used for pumping water to the summit, from a point 1,300 feet below. The water is raised 6 feet 6 inches by suction, and then forced through a 2-inch pipe to the summit level, at the rate of about 31 gallons per minute.

P. W. B.

Proposed Railway on the Jungfrau. By R. BODE.

(Wochenschrift des österreichischen Ingenieur- und Architekten-Vereines, 1890, p. 35.)

Two projects for this railway have been prepared, one by Mr. Köchlin, the builder of the Eiffel Tower, the other by Mr. Trautweiler; the latter only is the subject of this Paper. The line will commence at a point about 2 miles from Lauterbrunnen, at an elevation of 2,850 feet above the sea, and in a total length of 4 miles will reach a point 100 feet below the summit of the mountain, at an elevation of 10,690 feet vertically above the starting-point.

It will be made in four sections, all in tunnel, averaging 50 feet below the surface.

The first and steepest section, up the west face of the mountain, will be about 4,500 feet long, with an incline of 98 per cent.; the second section will be 6,000 feet long, with an incline of 48 per cent.; the third about 6,150 feet long, with a slope of 67 per cent., and the fourth and last section 4,600 feet long, with an incline of 33 per cent.

The tunnels will have a clear width of 8 feet 10¼ inches, and height of 9 feet 6 inches, with flat roof and cut-stone lining 8 inches thick. The line will be single-gauge, 3·28 feet, with double-rack rail in centre, and automatic brake gear. The carriages, lighted by electricity, have three compartments, each holding six persons, or eighteen in all, will project about 18 inches over the rail on each side, and thus just leave room to step out and pass along the line. The stations between each two sections of tunnel are cellar-like rooms in rock, arched over, and capable of holding from fifty to sixty persons, and each station is provided with a buffet. From the stations inclined passages, from 66 to 300 feet in length, will extend to the surface, for the benefit of passengers who may wish to halt on their long journey of two hours in tunnel, and enjoy the view. These passages will be provided with double or treble doors to exclude draughts. It will be a wire-rope line, the drum at the top being worked by compressed air instead of water; for it is stated that, as air must be pumped into the tunnels during their excavation for the workmen's sake, and continued after the line is opened, there will be economy in this arrangement. The compressors will be about 1½ mile distant from the starting-point of the line, and the air will be conveyed in wrought-iron pipes. The cost of the project is given at £230,000, and time of completing the line five years; and the returns are based on an assumed passenger-traffic of eight thousand per annum, at a cost for the return-trip of £2 12*s.* per head.

As might have been expected, strong objections to this undertaking were soon made by physicians, meteorologists, and also by the Swiss Alpine Club, and these objections may be classified as follows, viz.:—

The tunnels in winter—and even in unfavourable summers—will be full of snow and ice. The water trickling through into the tunnels will freeze, and on thawing in the spring season will work mischief. The cold and draughts in the tunnels will be unbearable. The difference of barometric or air pressure during the ascent will produce sickness and dizziness, and there will be a sad want of proper ventilation. No doubt whatever was expressed as regards the practicability of the engineering details of the work, but it was strongly maintained that the line could never pay. Mr. Trautweiler meets all these objections seriatim, and states that, as the line will be entirely underground, snow and ice cannot affect it; that the water trickling through will be of the temperature in the tunnel, which at a depth of 50 feet below the surface will never be at freezing point, and that such an amount of cold is much more favourable for working in than the excessive heat met with, for example, in the St. Gothard tunnel; that the side-passages, or ramps, will be closed by double or triple doors, and thus exclude draughts; that the changes of air-pressure are not so great or so sudden as in pneumatic foundations, where the workmen are suddenly subjected to a pressure of three or four atmospheres, under which they work for forty minutes without injury to health, whereas on the railway the difference of air pressure between bottom and top of the line is about one-third of an atmosphere, and the traveller has two hours to accommodate himself gradually to the change. As regards ventilation, Mr. Trautweiler has no anxiety whatever, for air will be continually pumped into the tunnels from below, and the longest of these is not one-sixth the length of the Arlberg tunnel. With reference to the financial results of the undertaking, the Author speaks confidently, and states that the position of the Jungfrau is specially favourable for Swiss passenger-traffic; for Interlaken is not only approachable by rail from Berne, but, since the opening of the Brünig line, from Lucerne also; and that, as the line from Interlaken to Lauterbrunnen is now being made, the Jungfrau mountain line will be in direct junction with the most attractive and most largely-visited parts of Switzerland, and he is of opinion that it will be as much frequented as the Gaisberg is from Salzburg, and the Mendel from Botzen, whatever the weather may be.

W. H. E.

The Air of the St. Gothard Tunnel. By R. Bechtle.

(Schweizerische Bauzeitung, vol. xv. 1890, p. 43.)

During the early days of the working of the Saint Gothard railway, when it was uncertain whether the natural circulation of the air would be sufficient for the removal of the smoke, or whether artificial ventilation might be necessary; a system of temperature observations was organized by placing thermometers in the fifteen refuge-chambers in the tunnel, which were observed and recorded at intervals of eight hours by the tunnel watchmen, who noted at the same time the strength and direction of the air-currents and the density of the smoke in the air, the external atmospheric conditions being simultaneously recorded at the meteorological stations at the Göschenen and Airolo ends of the tunnel. These observation-sheets were sent into the engineer's office monthly and at the end of the year. The results were plotted as curves for the Swiss Railway Department. The present Paper contains an abstract of the results of six years' observations—1883–1888—from which it appears that the maximum temperature in chamber No. 8, in the middle of the tunnel, has been practically constant 22°·8 to 23°·4 Centigrade, while the annual minimum shows a small continuous diminution from—

16°·4	in March	1883 to
16·0	February	1884
15·0	February	1885–6
14·8	December	1887
14·5	January	1888

During the driving of the tunnel the average annual temperature observed in the headings was as follows:—

——	1876.	1877.	1878.	1879.	1880.
Göschenen end—					
During boring	19°·4	21°·1	24°·0	26°·4	30°·3
After firing	20·8	23·4	26·0	29·3	31·2
Airolo end—					
During boring	23·1	25·0	25·8	28·2	29·3
After firing	26·6	28·5	29·3	30·7	31·0

Before the joining of the headings on the 29th February, 1880, the mean temperatures in the Göschenen end were 26°·6 and 29°·6, and in that of Airolo 29°·2 and 31°·6 respectively, as during the last month the amount of air delivered in the ends was largely increased, but this only reduced the air temperature to about 1°·7 below that of the rock. The latter was in February 1880—

At 7,635 metres in on the north side under 1,704 metres of cover, 30°·6
7,041 „ „ south „ 1,480 „ „ 29·4

The mean rock-temperature of the entire length of the tunnel was originally 23°·43, the mean air-temperature February 29, 1880, 21°·60; on February 11, 1881, 19°·3; and on February 11, 1882, 14°·2. These figures show very clearly the diminution in the mean natural temperature of the whole tunnel.

Later determinations of the rock-temperature made since the opening of the line gave the following results:—

Date.	7,300 metres N. in bore-hole 1 metre deep.		7,050 metres S. in boring 1·1 metre deep.	
	Air.	Rock.	Air.	Rock.
July 1882	20°·10	23°·9	21°·0	24°·5
July–August 1885	19·65	22·2	20·6	23·0
Diminution	..	1·7	..	1·5

As regards the movement of the air, the observations were confined to noting the direction of the current and estimating its strength, which was noted as strong, moderate, weak, or calm. The natural draught in the tunnel results from differences of air-pressure at the two ends, the wind blowing from the side of highest pressure, and its strength being proportional to the square root of the difference of the two pressures; the column of 36 metres due to the difference in the relative level of the two ends being sometimes in favour and sometimes against the prevailing wind, according as it is lighter or heavier than the external air. The combined effects of differences of temperature and moisture at the two ends resulted, during the five years' observations, in the following average distribution of the air-currents, the draught being either continuously north or south for some time, or changing from one to the other direction at short intervals. In the latter case there are of course periods of calm, but none of them have ever lasted for more than half a day.

Year.	Days of prevailing North Wind.		Days of prevailing South Wind.		Days with alternating North and South Winds.	
	Winter.	Summer.	Winter.	Summer.	Winter.	Summer.
1883	70	75	45	29	66	80
1884	60	82	56	42	67	59
1885	51	80	64	33	67	68
1886	55	70	60	54	67	59
1887	65	79	45	40	72	64

Winter signifies the period October to March, and summer April to September inclusive.

From these figures it appears that northerly wind is most prevalent in the summer, while in the winter months the draught is tolerably equally divided between north and south. The days on which rapid changes in direction are observed differ but slightly with the season.

The prevailing external wind at the tunnel stations appears to have no effect upon either the duration or the strength of the current in the tunnel, neither is the distributing influence of a passing train acting as a piston more than local and insignificant.

The smoke observations were classified into whole and half-days of smoky air; transitory smoke and air free from smoke. These are plotted upon curves, but given without numerical data. From these figures it appears that continuous smoky days are more prevalent at the south than at the north end, and in summer than in winter; and that the number of clear days is similarly larger at the north than the south end, although the difference is but slight. The middle of the tunnel is completely free from smoke for only a very small number of days in the year; but, on the other hand, the number of entirely smoky days is much less than at the ends, while the effect of the transitory smoke is most constant at that point. The most unfavourable conditions are observed on days when the wind is only slight or unsteady in direction. The work necessary for the maintenance of the way, &c., is, as far as possible, confined to days of strong prevailing winds in one direction, or the night hours, when the traffic is confined to two express trains and the smoke is at the lowest. Passengers travelling through with the carriage-windows shut suffer no inconvenience from smoke. The six years of observation having proved that the ventilation of the tunnel is practically continuous in one direction or other, the practice of recording the smoke has been discontinued, and the Author considers that there will be little further utility in continuing those on temperature and air-movement.

H. B.

The Sliding Railway. By C. Barre.

(Mémoires de la Société des Ingénieurs Civils, January 1890, p. 33.)

The hydraulic, or sliding railway, the invention of Mr. Louis Dominique Girard, is based upon two principles, sliding and hydraulic propulsion. The vehicles are supported by rectangular slides, replacing the wheels of ordinary vehicles, which rest on rails of the same width. During the motion of the vehicle, a film of water under pressure is forced between the slides and the rails, so that there is no point of contact between them. The tractional resistance is thus reduced to a minimum not exceeding 1 kilogram per tonne, or, say, 2·2 lbs. per ton.

All the vehicles of the train thus sustained are pushed forward by horizontal jets of water under pressure issuing from fixed ajutages placed at intervals, and acting upon a rectilineal turbine placed under the vehicles in the axis of the way, and from one end of the train to the other. The ajutages—called propellers—are opened by the first vehicle of the train in passing, and closed by the last. They are mounted on a conduit which extends over the whole length of the line, and is charged with water under, say, 10 atmospheres pressure, from a natural fall, or by pumps worked by steam-power. The supply of water for the slides is derived either from the central conduit, delivering water into a special tender by suitable cranes, under pressure, or is picked up at speed into special reservoirs under the vehicles.

The vehicles are very light compared with ordinary vehicles on wheels; and there is no additional weight corresponding to that of a locomotive and its tender. The dead-weight, so called, is only one-third of that of a system of wheeled vehicles; whilst the resistance per ton weight is much less in the former than in the latter case: resulting, it is estimated, in a saving of about 66 per cent. of the cost for traction. The cost of maintenance, also, is considerably reduced.

A short line of sliding railway was laid at the Esplanade des Invalides, in connection with the Paris Exhibition of 1889, and was worked during a period of four months. Preliminary experiments were made with a single slide, 17·3 inches long, 8·66 inches wide, loaded to the extent of 2,332 lbs. including its own weight and that of the platform carrying the load. The pressure in the compressed-air reservoir employed in the trial was from 2 to 3 atmospheres; but the pressure under the slide was constant at 1·80 atmosphere; and it is argued that the active surface of the slide was less than the total surface; that it was only 91 square inches, or a rectangle about 15 inches by 6·3 inches; of which the product of the perimeter by the lift of the slide—0·75 millimetre, or about $\frac{1}{30}$ inch—is the real orifice of outflow. The calculated outflow is the product of the velocity due to the pressure by this orifice, or about 3·4 gallons per second. But the actual outflow was only about one-fifteenth of this quantity.

The resistance of a single slide to sliding does not amount to half a kilogram or 1·1 pound per ton; and a well-balanced slide would slide down an incline of 1 in 2,000.

At the Invalides the train consisted of two carriages and a tender, supported upon fourteen slides. Two accumulators carried on the tender and holding the water for sliding, were each 28·35 inches in diameter, 9·84 feet in length, 43·14 cubic feet in capacity. They were charged with water to a level not exceeding two-thirds of their capacity. The air, compressed to 9 atmospheres, occupying the remaining third, utilized by its expansive action all the water in the reservoirs. The adjustment of the supply of water not to exceed two-thirds of the capacity was a point of importance for the properly-sustained action of the compressed air. Slide-water was consumed at the rate of one quart per slide per second. The propeller jets delivered 14 gallons of water per minute under a pressure of 10 atmospheres, causing a pushing pressure of 99 lbs.

At the outer side of each rail, another and smaller rail, of U section, was laid, serving to guide the slides, and keep them on the rails. At the points, these guide-rails are pinned to one of their supports, and are shifted by the hydraulic cylinders, making a passage from one way to another, without any interference with the carrying rails.

The accumulator-pumps were worked by a 50-HP. steam-engine; with which the power required did not exceed 35 HP. The total distance run during the four months' working amounted to 744 miles; no apparent wear of the pattens had taken place. The consumption of coal was at the rate of 5½ lbs. per double journey, going and returning. The line comprised an incline of 1 in 25, 118 feet in length; a level 42½ feet in length; and a reverse incline of 1 in 50, 118 feet long. The speed was 26¼ feet per second, or 18 miles per hour. It is considered that speeds of from 100 to 120 miles per hour can be attained.

D. K. C.

Improvement-Works on the River Rhone. By L. Clavard.

(Nouvelles Annales de la Construction, pp. 10 *et seq.*, 1890.)

The works described in these articles are still in progress, but as portions of them have been in existence some time and stood the test of both floods and droughts, the success of the complete scheme seems assumed, and the Author thinks a similar course of treatment applicable to other similar rivers.

The course of the river is divided into three sections:—

(1) Above Lyons 120 miles not navigable.
(2) Below Lyons to Arles, 175 miles } navigable.
(3) Below Arles to the sea estuary, 30 miles }

The regime of the river is described in considerable detail. The main feature of it is the fact that very heavy floods occur from the melting of the snows of the Swiss mountains where the main stream takes its rise, modified by the fact that the principal affluents are not snow-fed, and therefore do not coincide with the main stream in their periods of flood. The bed of the river is of gravel easily eroded, varied at a few points by isolated rocks emerging from the bottom. Until the new works were undertaken, every flood led to a new channel being opened in one part or another of the stream. The object of the work has been to fix the channel of the river and put an end to erosion of the banks and bottom, and the result has so far been most satisfactory. A longitudinal section of the river in any part shows an alternation of deeps and shallows, the deep occurring in the middle of a curve (in plan) at its outer side, and the shallow at a point of inflexion between two successive curves. The Author explains how isolated dredging in the shallows reduces the level of the reach above, and generally tends on the whole to reduce the navigable depth rather than increase it. Illustrations are given of the very large variations in velocity of flow that exist in short distances depending on the changes of depth, the curvature of the channel, and other causes, and of the tendency of these variations to disappear as the river rises. The effect of dredging in one of the shallows is to lower the water-level and diminish the velocity at that point, and the lowering of level extends through the next reach upwards to the nearest shallows above at which the slope and velocity must therefore be increased and the depth of water diminished. Similar effects are shown to follow in many cases from an isolated embankment narrowing the stream in a shallow. The first effect is of course to raise the level in the shallow. This increases the velocity and sets up an erosion of the bottom which goes on till equilibrium is restored. The net result is a water-level which will in general be lower than the primitive level over a great part of the distance affected by the training-wall and a diminished depth of water for navigation. As an illustration of these effects a description is given of a certain length of about 6 miles of the Rhone, on which various isolated embankments were made at different times, between 1858 and 1874, showing that while the immediate effect was beneficial, the indirect results were such as to diminish the available depth in the end. It is seen therefore to be essential, in disturbing the conditions of a river-bed liable to erosion, to determine what the condition of equilibrium will be after the new works have produced their full effect, and to make sure that a remedy directed to a specific evil will not produce greater evils elsewhere.

The articles are accompanied by numerous diagrams and drawings, and are to be continued in future numbers.

C. F. F.

The Removal of Obstructions to Navigation on the Lower Danube.

(Wochenschrift des österreichischen Ingenieur- und Architekten-Vereines, 1890, p. 41.)

The works proposed are of three kinds, viz.:—

1. The excavation of channels through the rocks across the river.
2. The construction of weirs.
3. The building of a navigable canal at the "Iron Gates."

The first obstruction met with is the rocky bank Stenka, below Moldova. A channel will be made through this, 197 feet wide at bottom, and 6½ feet below mean water-level, which will entail the blasting and removal of about 9,600 cubic yards of rock. The next obstructions are the Kozla bank, 9¼ miles below Stenka, and another named Dojke, a little further down. These obstructions will be removed by the construction of a navigable channel on the left bank of the river, which will necessitate the excavation and transport of 85,540 cubic yards of material. About 5½ miles below the Dojke bank is a bed of rocks called Izlas, and further down another named Tachtalia, and from this point down to the Greben Spit are some rocky ledges, visible only at lowest water-level, and very dangerous to navigation. A channel, involving the blasting and removal of 60,840 cubic yards of rock, will be made in this section of the river. A similar channel, with a cubic content of 41,600 cubic yards, will be cut through the rocks which form the rapids called Jucz, about 5 miles below Swinyicza, and other rocky ledges have to be cut through in the navigable line of channel involving an excavation of 13,000 cubic yards of material. The rocks mainly consist of granite, mica slate with quartz, limestone, with veins of slate and porphyritic serpentine. On an average these rocks have to be blasted out to a depth of 3 feet, and the velocity in the different sections varies from 8 to 15 feet per second.

The Greben Spit, above mentioned, reduces the river's breadth at mean water-level from 760 to 460 yards, and at low-water (owing to the projection of a ledge of rocks from the left bank) to about 220 yards, but immediately below Greben the river widens out again to about 1,530 yards. There are consequently falls or rapids here, and these are a serious hindrance to navigation; moreover, for more than 1½ mile between Greben and Swinyicza there is not sufficient depth of water. It is therefore proposed to cut through the Greben Spit, and to build a weir with crown 6½ feet above the raised water-surface, which will reduce the falls above specified and increase the depth at low-water. This weir will be 6,780 yards long, with breadth of crown of 10 feet, and side-slopes of 1 to 1½, and for its construction 624,000 cubic yards of stone will be required.

Another weir will be built below Jucz 4,290 yards long, breadth of crown of 10 feet, side-slope up stream 1 to 2, down stream 1 to 1, the whole faced with cut stone. For the body of the weir 156,670 cubic yards of stone will be required, and for the stone revetment about 50,000 cubic yards.

At the "Iron Gates" it is proposed to construct a navigable canal along the right bank of the river. The bottom of this canal will be 6½ feet below mean water-level, breadth 262½ feet, and length 2,260 yards. The embankment on left side of the canal (that is towards the river) will have a top breadth of 13 feet, side-slope towards the river 1 to 2, towards the canal 1 to 1½, while the embankment on right side will have a top breadth of 20 feet (to serve also as a footpath), side-slope towards the canal 1 to 1½, and outer slope 1 to 2. The body of the dams or embankments will be of rubble stone, but crown and slopes will be faced with cut stone. The construction of this canal will require the excavation and removal of about 320,000 cubic yards of rock, of which amount 52,000 cubic yards will be required for the embankments.

The works are to be finished by the end of 1895, and are estimated to cost about £830,000.

W. H. E.

The Observatory and Tide-recording Station of Marseilles.

By A. LALLEMAND.

(La Nature, Feb. 8, 1890, p. 145.)

In the year 1884 the general committee of levels in France decided to construct at a point on the Mediterranean coast, near Marseilles, a tide-recording station, with the object of determining the mean sea-level with the aid of the most accurate modern appliances obtainable. The site chosen for the observatory was protected from the influence of river-water, and, as far as possible, from other disturbing influences. The buildings, of which illustrations and sections are given, were constructed by the engineers of the port of Marseilles. The chief apparatus, of which woodcuts are given, is a Reitz totalising tide-recorder, modified by Mr. C. Lallemand. By means of a planimeter, the apparatus itself calculates the area of the diagrams as they are produced, which considerably simplifies the work, while increasing the accuracy of the observations. The curves are traced in duplicate by a diamond point upon a strip of paper covered with a layer of black varnish, the lines thus appearing white upon a black ground. The observatory is also provided with registering barometers and thermometers.

W. F. R.

Irrigation in its Relation to the Pastoral Industry of New South Wales. By H. G. M'KINNEY, M. Inst. C.E.

(Journal and Proceedings of the Royal Society of New South Wales, 1890, p. 75, 2 maps.)

The total area of land in New South Wales is estimated at 196,000,000 acres, and of this area 168,000,000 acres is devoted to pastoral purposes, with very precarious results owing to frequent droughts. Only 1,042,000 acres is under cultivation. These figures show the importance of the consideration whether irrigation cannot be made to assist in developing the pastoral resources of the colony. As an instance, the Author mentions a case where unirrigated land on the Lower Darling, which could scarcely support one sheep to every 10 acres, was found, when laid down in lucerne and irrigated, became capable of supporting more than twenty sheep to 1 acre. In order to reduce the losses entailed by drought, sheep are frequently sent to the mountains, or to other localities where pasture is obtainable; but this course involves considerable expense and much risk, and frequently results in the loss of a serious proportion of the sheep. The total production of wool in New South Wales in 1888, an unfavourable year, was 205,000,000 lbs., and assuming that on an average for the whole quantity the diminution in value, owing to the nature of the season, amounted to $\frac{1}{2}$*d.* per lb., the loss would amount under this head to £427,000. Besides the prejudicial effects of drought, wool is seriously diminished in value by the break which is caused by a sudden change in the character of the season. The alteration in the quality of wool which takes place immediately after the break-up of a protracted drought is at once apparent, even to the unpractised eye.

In New South Wales the best rivers for irrigation purposes are the Murray and the Murrumbidgee. The district commanded by them includes only the plains between them, and a moderate area to the north and west of the Murrumbidgee. The only portion of the colony in which irrigation can be carried on with regularity, and on an extensive scale, is in the part of southern Riverina commanded by these rivers, although the Author believes that the country west of the Dividing Range is, under favourable circumstances, susceptible of remunerative irrigation. The methods recommended are: 1st, the irrigation of extensive areas of the native grasses; 2nd, the irrigation of limited areas of lucerne, or other crops for fodder.

The former system is in natural operation on a large scale on the Lower Murrumbidgee, as well as on a moderate scale on the lower parts of several others of the western rivers of New South Wales. This is precisely the same process which irrigates and fertilizes the valley of the Nile. In some of the cases in which the process is exemplified in New South Wales, the inundations due to flood-waters form the chief security of the "pastoralists" whose lands are thus naturally irrigated. As generally happens in the case of rivers flowing through alluvial plains, the banks of the lower parts of the rivers mentioned are higher than the land adjoining. Hence, in order to divert supplies of flood-water so as to irrigate by gravitation, it is only necessary to make cuttings from the rivers with a moderate rate of fall, and extend them till they run out at the level of the natural surface. Several cuttings of this kind were made on the Juanbung Run by Mr. Tyson, and one of them alone is stated to have cost £14,000. How profitable irrigation of the native grasses can be made under such favourable circumstances is very clearly shown in the case of Mr. J. L. Gwydir's experience. In the Corrong Run, with an expenditure of very little over £1,200, Mr. Gwydir succeeded in irrigating over 17,000 acres of grass-land during every flood in the Lachlan. Taking interest and cost of maintenance together at £150 per annum, the cost of irrigating an acre amounted to only $\frac{3}{17}$*s.*, or slightly over 2*d.* In this case the profits of the first year's operations more than covered the entire outlay. Before irrigation the land referred to barely sufficed for four thousand sheep; after the system of watering was adopted, it supported twelve thousand sheep and two hundred horses, besides fattening one hundred and fifty head of cattle.

Irrigation of the native grasses by pumping, at a gross cost of about 2*s.* 6*d.* per acre, has given a very satisfactory return under favourable circumstances in Victoria. The pumping-plant in such cases was erected primarily for the irrigation of crops, but at such times as water was not required for the crops the supply was turned on to the grass-lands. Under these circumstances the Author maintains that the profitable irrigation of the native grasses is therefore not a question for debate, but an accomplished fact; and the only point for consideration in connection with it is the nature of the circumstances under which it is practicable.

After some remarks on the rates of water for irrigation, the process of flooding pasture land, and the production of fodder by irrigation, the Author proceeds to consider the case of the River Darling. He states that the most important functions of that river are threefold, namely: 1st, the provision of reserves of fodder for the western district; 2nd, the flooding of large areas of pasture; and, 3rd, the provision of a permanent highway for navigation. To effect the last of these objects, a series of weirs and locks is indispensable, and the raising of the water-level by this means will materially lessen the cost of pumping for the irrigation of crops. The circumstances of the Darling are extremely favourable in some important points to the construction of works for the purposes referred to. With a series of weirs at suitable intervals, the river at ordinary heights would consist of a succession of reaches of almost still water. The same weirs would also hold up the water in the river to such heights, that flooding the land by gravitation could be carried out in the manner already adopted on the Lower Lachlan. The conservation of the waters of the Macquarie is stated to afford "remarkably favourable conditions for the diversion and storage of flood-water," and the Author gives at length the conclusions of the second report of the New South Wales Water Commission, which advocates the judicious expenditure of £300,000 in diverting supplies from the Macquarie, and distributing them between that river and the Bogan.

The Paper concludes with some general remarks on the progress of water conservation in Victoria, the principal irrigable areas in New South Wales, water legislation, the examination of engineers, the causes of the backward state of water conservation, and statistics relating to losses therefrom.

In the discussion following the Paper the importance of the subject was generally admitted. In regard to the suggested interference with navigation which might result from the removal of so large a quantity of water from the rivers, it was stated that in Victoria people were quite reconciled to the idea of navigation being seriously interfered with, believing that much greater good would result from irrigation.

F. G. D.

New Water-Supply for Paris. By HENRI MAMY.

(Le Génie Civil, vol. xvi. 1890, p. 372.)

An important addition to the spring-water supply for Paris is under consideration by the Legislature, and has been approved by the Committee which examined it.

Paris has at present two independent water-supply systems, viz., spring-water to the amount of nearly 31 million gallons per day for domestic purposes and a separate service of river-water for manufacturing and municipal purposes amounting to nearly 100 million gallons per day. Now the former supply often becomes unequal to the demand in hot weather, and it has been the custom at such times to supplement it by an addition of river-water, which is impure and which has produced markedly injurious effects on the public health. The required supply of spring-water is estimated at 22 gallons per day per head for a population of two and a quarter millions, which requires an addition to the existing supply of 24,000,000 gallons per day (*sic*). One means of meeting the difficulty which has been recommended is that of laying on to the houses a service of river-water to be used for all purposes except drinking, cooking, &c.; but besides the risk of drinking river-water by mistake to which the population would be exposed, the cost of the new house-connections, and of raising the river-water to serve the upper storeys, would be £5,600,000 against £1,440,000 at which the new supply in estimated. The Paper describes alternative sources of supply which have been examined, and describes the one finally agreed on. It is in Lower Normandy, in the valley of the River L'Avre, 62 miles from Paris, and can supply the requisite quantity of water by gravitation with an available head of 328 feet at Paris (above the Seine mean-level). The route of the conduit is described. The slope is to be 2 feet per mile, giving a speed of 3·3 feet per second. The conduit is to be of circular pipes about 5 feet 8 inches in diameter, with an outside lining of masonry 8 inches thick, and an inside coating of $\frac{3}{4}$-inch cement over the lower two-thirds. About 5 miles of the conduit is under pressure, and, of course, the pipes are there lined all round with cement. The aqueduct will discharge into a new reservoir at Montretout of a capacity of 88,000,000 gallons.

A map of the district through which the aqueduct will pass accompanies the Paper.

C. F. F.

The New Reservoirs at Montmartre, Paris.

(Nouvelles Annales de la Construction, 1890, p. 18.)

The new Montmartre reservoirs occupy an area of 2,750 square yards. They have a capacity of 14,390 cubic yards, of which 8,110 cubic yards are for well-water and 6,280 cubic yards for river-water. They supply the higher parts of the 18th arrondissement, and consist of two separate buildings, one of which has water stored on three floors and the other on two. The lowest storey of both reservoirs contains river-water, the storey next in height contains well-water, and the highest storey of the three-storeyed building distributes well-water to the most elevated part of the hill of Montmartre. There are thus practically five distinct reservoirs, each of which can, when necessary, be cut off without affecting the others, for examination, cleaning, and repairs.

The foundation is on fine yellow sand, rendering it most important to avoid any leakage of water into the soil. The precaution adopted was to construct the foundations in the form of vaults. The floor of these vaults is covered with an impervious plaster, and serves to collect and carry off any leakage that may arise from the reservoirs. A similar process is employed with the side walls, which are partly below the ground level. A drain is built in the wall which intercepts any leakage, and delivers it into the vaults below the reservoir. The lowest storey of the larger reservoir is designed for a depth of water of 16 feet 5 inches, and is arched to a height of 19 feet under the crown, the span being 9 feet and the piers 4 feet 9 inches in mean thickness. The intermediate storey has a depth of water of 11 feet 6 inches, and has a height of 14 feet 6 inches under the crown of the arches, which are of a span of 10 feet, with piers of 3 feet 4 inches mean thickness. The highest storey has a depth of water of 8 feet 9 inches, and a height of 11 feet under the crown of the arches, which are in this case of brick 11 feet 7½ inches in span with a rise of 2 feet 9 inches. The piers are 1 foot 6 inches in thickness. The general arrangement of the smaller reservoir is similar to that of the larger one. The outer walls of the larger building are designed to resist the pressure of the full depth of water in all the storeys without allowing for the support of the ground outside or of the pillars within. Under these circumstances the least distance of the curve of pressure from the face of the wall is 2 feet 3 inches, and the maximum pressure at the outside edge of the wall is 137½ lbs. per square inch. The partition wall between the two reservoirs is designed to resist the pressure from either reservoir being fully loaded when the other is empty. The maximum pressures on this wall and on those of the smaller reservoir do not differ much from that above quoted. Iron ties between the walls 3 inches by ¾ inch in section are also introduced. The maximum load on the piers is 180 lbs. per square inch, and the mean load on the foundations is

2·2 tons per square foot, except over one part where there is made ground close to the building, and where the foundation was extended to reduce the pressure. The foundation is of concrete composed of 3 parts of gravel and 2 parts of a mortar made from 1 part of Portland cement with 3 parts of sand. The walls and piers are built of masonry in Portland cement. Details are given of the arrangement of supply pipes, and service-mains, and of the valve chambers. The cost of the works was £40,000.

The Paper is illustrated by two large plates of drawings.

C. F. F.

New Pumping-Station at Bercy, Paris. By R. AVDRA.

(Le Génie Civil, vol. xcvi. 1890, p. 353.)

In the foregoing abstract the new reservoirs at Montmartre are described.[1] The present notice deals with the pumping-station from which these reservoirs are supplied. The water is taken from the Seine by means of two siphons of cast-iron, which deliver it at the pumping-station in wells, whose floor is 13 feet 1½ in. below the normal river-level. Provision is made for emptying and cleaning the siphons, and, by means of small pipes connecting the highest points of them to the pump-barrels, all accumulation of air is prevented. The water is raised from these wells by vertical pumps to cisterns about the level of the highest floods of the Seine, and from these cisterns the horizontal pressure-pumps are supplied. The head of water with mean river-level is 184 feet in all. The capacity of the pumps in ordinary working is over 11,000,000 gallons per day. There are four sets of pumps, one vertical and one horizontal forming a set driven by one engine. Each engine is of 150 HP. effective, and is of the Wheelock type with plane balanced slides. Each can act independently of or in combination with any other. The steam cylinder is of 31½ inches diameter, the horizontal plunger 16⅛ inches, the vertical piston 39¾ inches. The steam-piston and horizontal plunger have a common stroke of 63 inches. The number of revolutions is 22½ per minute. The site being made on ground overlying peaty mud, the foundations were piled and a masonry floor 3 feet 3 inches thick laid over the whole site, in which the pile-heads were buried. There are eight water-tube boilers in four groups of two each. The tubes are 4⅜ inches in diameter and 15 feet long, with heating-surface of 1,076 square feet, and grate 5 feet 5 inches by 4 feet 2 inches. The boilers work at 85 lbs., and can supply each 4,000 lbs. of steam per hour. Six will supply the engines, leaving two for cleaning and repairs.

There are two pressure-mains, each 23½ inches in diameter and

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[1] *Ante*, p. 31.

about 3¾ miles in length. The cost of the works, not including land, was £36,000, or £60 per HP. measured by water raised. The works were commenced in July, 1887, and the first engines started in May, 1889.

The Paper is illustrated by one two-page plate of engravings.

C. F. F.

The Water-Supply of Vienna. By A. FRANK.

(Gesundheits-Ingenieur, 1890, p. 1.)

The authorities of Vienna, who have to face a deficiency in the drinking-water supply every winter, have determined to reinforce the existing supply, which falls short of the minimum daily volume needed of 5,100 cubic metres[1] by 1,130 cubic metres; the joint capacity of the Hochquellen and the Pottschach Springs being only 3,970 cubic metres per diem. The Author gives an account of the attempts made in the past to obtain pure supplies of spring-water in the Vienna Neustadt district, and describes the new project to secure deep spring-water from the Neustädter Steinfeld. This district, which is a portion of the Vienna inner-alpine tertiary basin, extends for about 57 kilometres in length by 11 kilometres in average breadth. The soil is a diluvial limestone-breccia, which rests upon a very deep-lying impervious stratum. Into this breccia soaks the rainfall of an area of 1,413·9 square kilometres, and finds for the most part a subterranean discharge, as only a small portion is accounted for in the waters of the Pitten, Schwarza, and Leitha, and the Hochquelle springs. Generals Sonnklar and Streffleur, as far back as 1859, drew attention to this district, and in 1864, a prize of 100 ducats was adjudged to Mr. Karlitschek for a scheme prepared in 1861, dealing with this source of supply. The quality of the water, which has been many times investigated, is very good, varying as it does in hardness from 13° to 15°, and having an average temperature of 9° to 11° Centigrade. The Water Company has acquired an area of 230 hectares. The subsoil water, which flows at a mean velocity of 3 millimetres per second, attains a maximum daily volume of 3 millions of cubic metres; the minimum volume being 0·56 million cubic metres. Of this only 1·2 cubic metre per second, or 103,680 cubic metres per diem, is to be diverted. The water is to be collected in a concrete gallery or adit 7,050 metres in length (7,710 yards), ending about 2 kilometres to the southward of Wiener Neustadt. The adit is formed at a depth of from 15 to 28 metres below the surface, and 4 metres beneath the lowest subsoil water-level. The internal dimensions of the adit are—4·5 metres high, 3 metres wide, fall, 0·157 metre per thousand metres. For the

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[1] 1 cubic metre = 220 gallons.

purpose of inspection and maintenance there will be seventeen manholes. At the end of the gallery there is to be a collecting reservoir formed of concrete in two compartments. The discharge of the water from the gallery into this reservoir is regulated by sluices, and the water in it will be kept at a nearly uniform level. From the first compartment of the reservoir the water flows into the second at an adjusted rate of 1·2 cubic metre per second. The sill of this reservoir is 262·5 metres above datum. By reference to a plan the course of the main and the position of the various subsidiary reservoirs is explained. The latter, eighteen in number, vary in capacity from 49,500 to 50,000 cubic metres. The pipe system extends to a total length of about 520 kilometres varying in diameter from 1,000 to 80 millimetres. The price for water supplied by gravitation is to be 1 kreutzer per hectolitre (9*d.* per 1,000 gallons), or for high-pressure service-water, 1·2 kreutzer per hectolitre (11*d.* per 1,000 gallons). The works have been put in hand, and will, it is expected, be in operation in 1892.

G. R. R.

Extension of the Main Reservoir of the Vienna "Hochquelle" Supply at Rosenhügel.

(Wochenschrift des österreichischen Ingenieur- und Architekten-Vereines, 1890, p. 58.)

Originally the reservoirs supplied by the "Hochquelle" had a storage capacity only just sufficient to meet the varying daily demands, but an extension of the reservoirs was soon found necessary to meet the demands of an increasing population, and in order to supply the suburbs of Vienna also. Consequently the Common Council decided in 1886 that the storage capacity of the reservoirs should be increased up to a total of nearly 53 million gallons, and in furtherance of this scheme the Laarberg reservoir was enlarged in 1866–67, the Weinerberg in 1887-88, and that of Rosenhügel, near Speising, in 1887–89. But these additions do not fully make up the 53 million gallons, therefore a further extension of the Rosenhügel reservoir is contemplated, the Schmelz reservoir will be furnished with a new basin and pumping-station, in order to supply the higher-lying suburbs, and there will be an addition to the storage capacity of the Laarberg reservoir. The reservoir at Rosenhügel receives the supply direct from the Hochquelle, and distributes it to the other reservoirs, and the new reservoir is connected with the former one by two pipes, each having a sectional area of 10¾ square feet, furnished with sluices to regulate the supply. The extension works cover an area of about 3¼ acres. The height of water-surface, when the reservoir is full, is 286 feet above zero of the gauge at the Ferdinand Brücke, and the depth is 12½ feet.

The foundations, which, on account of the firm subsoil, are not deep, are built partly of concrete, partly of masonry, and partly of brick. The bottom consists of two courses of brick in mortar, over which is a course of concrete 18 inches thick, and on that a 2-inch layer of Portland cement rubbed smooth. The walls and arches are of brick in cement, and the two hundred and sixteen pillars supporting the arches are of granite. All walls, piers, and arches are pointed with Portland cement; over the arches a layer of clay is firmly tamped down to receive a brick flooring, and on this is a 6¼ inch layer of cement concrete covered with asphalt and felt. The whole height of the roofing is, on an average, about 5 feet above the crown of the arches. The surface is planted with grass, and the rain is led off by ditches into the overflow channel.

The bottom of the reservoir has a very slight fall, to enable any foul water (when the reservoir is being cleaned) to run off into cisterns, whence it is led by pipes into the overflow channel. The admission of water into the new reservoir is regulated by four sluices, and the delivery to the town by a pipe leading into the existing main.

In carrying out the work about 120,000 cubic yards of material, including 22,000 cubic yards of rock, had to be excavated or blasted, and removed. The amount of masonry and brickwork walling is 15,000 cubic yards, and for the arches 11,000 cubic yards, and the total amount of concrete 10,000 cubic yards. A surface of 28,000 square yards is laid with Portland cement and polished, and for mortar 13,840 bushels of lime cement, and 16,000 bushels of Portland cement were used. The works were commenced on the 1st of June, 1887, and completed on the 30th of September, 1889. In the first year the greater part of the earthworks and the outer walls were completed, in the second year the remainder of the earth and rockwork, and the walling, together with the vaulting, and in the third year the roofing and tamping, and filling in of the arches, also the construction of the overflow channel, and the laying down of the pipes. The total cost, exclusive of purchase of land, was £51,000, or £3 5*s.* per square yard of area covered by the works.

A Plate accompanies the Paper, showing longitudinal and cross-sections of the new reservoir.

W. H. E.

Observations and Experiences of Subsoil-Waters.

By Professor F. Steiner.

(Wochenschrift des österreichischen Ingenieur- und Architecten-Vereines, 1889, p. 392.)

These observations were made in continuation of previous observations on the Bilin chalybeate springs, with a view to a knowledge of the nature of subsoil-waters generally. Such waters, it is stated, are met with not only as underground lakes, but as running streams, which follow generally the laws applicable to all rivers and streams—the conditions being, however, in some respects distorted or modified, especially as regards frictional resistance and velocity. For although 6½ to 10 feet per second may not be regarded as an unusual velocity for rivers, it might take underground streams an hour to travel over the same distance, thus showing a velocity three thousand six hundred times less; yet, on the other hand, subsoil waters are sometimes met with having a fall of 1 in 20, or 1 in 16—that is, considerably greater than that of rivers in general. And again, as regards backwaters, and the heading-up due to banks or weirs, these subsoil streams are subject to the same laws as rivers; but the most interesting property of subsoil waters in general is that there is no chemical homogeneity in them; the waters consisting, in fact, of separate filaments of different chemical composition, due to outside influences. In this respect, however, similar results are to be observed in large rivers; for example, the flow of the river Inn into the Danube affects the character of the latter river for many miles; and the Moldau at Prague is another prominent instance, for the water of this river, at different points, is of different chemical composition, that along the right bank being much softer than that along the left bank, and the upper layers of water softer than those deeper down. Under the Author's superintendence, a boring was made at Bilin through diluvium, chalk, and gneiss, down to a depth of 426 feet, when an abundance of good mineral water was obtained, the yield increasing with the depth. The rise of the water in the bore-shaft was measured automatically, and its curve graphically shown—the time giving the abscissa, and the rise during that time the ordinate. This curve was a regular parabola, showing that the rise was uniform, and not affected by feeders under different pressures; between 380 and 426 feet of depth the curve was stationary, showing that no new springs had been met with. Wishing to tap this chalybeate spring, and to lead it to the sloping ground-surface, a tunnel was being driven in the chalk towards the bore-shaft, when fresh water was struck of a different chemical composition from the Bilin mineral water, and it was at the same time observed that the surface of the water in the bore-shaft was steadily sinking; showing clearly a connection between the chalybeate water deep down in the gneiss, and the subsoil stream in the chalk, flowing at a depth of only 15 to 20 feet below the ground-surface, and also explaining why other wells that had been sunk above the trial-boring showed different water-levels. The results of the Author's observations and experiences of subsoil waters generally, led him to consider the question of the water-supply of Prague, which is now very deficient, being restricted to house-wells and the filtered water of the Moldau. A project has been under consideration for years past, and trial-borings have been made, and the water-levels in each well observed; these have shown a very great difference in the degrees of hardness of the water, though all the borings were apparently made in a connected subsoil area; and further experiments proved that the water at the left bank of the subsoil stream was considerably harder than towards the centre. This hard water, it was thought, might be due to the supply coming through chalk strata, and the varying degree of hardness owing to the deposit of carbonate of lime in passage through the earth; but it is stated that the amount of hard water met with is entirely disproportionate to the amount of rainfall in the particular locality, and that the subsoil streams at Prague lie deep down in the earth, and are of different chemical composition. These considerations, it is stated, did not furnish much light on the question of deep boring at Teplitz, where there are subsoil warm springs, of volcanic origin, extending over a large and deep-lying subsoil area, and where deep boring is of advantage, but the observations on the Bilin chalybeate springs prove that subsoil waters really play an important rôle in the province of medicinal waters, which has been hitherto ascribed to volcanic origin.

W. H. E.

Experiments on the Efficacy of Filtration through Sand.

By Dr. CARL FRÄNKEL and C. PIEFKE.

(Zeitschrift für Hygiene, vol. viii. 1890, p. 1.)

In the early months of 1889, Berlin was visited by an epidemic of typhoid fever which extended over a wide area, and which, from the middle of January to the middle of April, caused some seven hundred cases to come under the notice of the authorities. By reference to a map it is shown that this outbreak must have been wholly unconnected with the levels of the subsoil water, as in lieu of extending over a district parallel with the course of the river, which would follow the lowest levels of the subsoil water, it took a direction exactly the opposite, and attacked the western portions of the town, leaving the east end of Berlin untouched. For this reason the water-supply became suspected, and Virchow, at the meeting of the Berlin Medical Society on the 19th June, pointed to this as a possible cause of the epidemic. The Authors mention several matters which may have contributed to the evil. The waterworks near the Stralau Gate possess eight open and three covered filtering-beds. During the long-continued frosts of the winter months the open basins become frozen over, and in time become useless, so that the whole of the effective filtration has to be carried out in the three covered basins, which in consequence are worked at far too great a pressure. Thus, in February last, a rise in working speed took place of from 130 millimetres to 160 millimetres per hour, and on the twelfth of March the maximum rate of filtration of 224 millimetres per hour was attained. The formation of a layer of bacteria on the surface of the sand is found to greatly retard the rate of filtration, and when the head of water is increased, it tends to drive the micro-organisms through the pores of the filtering material, and ultimately into the filtered water. This state of things is, of course, attained all the more quickly when the water to be filtered is very impure. By reference to a graphic diagram, the numbers of germs present per cubic centimetre of filtered water during the period in question are indicated. These rose rapidly from about one hundred in the middle of January, to over ten times the amount in February, and attained, during March, the enormous total of upwards of four thousand per cubic centimetre. At the beginning of April, when the whole of the filter-beds were again in operation, the numbers of germs at once sank to the normal level. During these months the waters of the Spree were highly charged with bacteria, the numbers of germs, from January to March, often exceeding one hundred thousand per cubic centimetre. Though the presence of typhoid germs has not been demonstrated therein, the water-supply of Berlin was manifestly extremely impure.

Much suspicion was expressed respecting this state of things, and the Authors were commissioned by Mr. Koch to investigate whether it might be possible to spread the germs of infectious diseases through the mains of the Water Company. For this purpose they undertook a series of experiments, all the necessary assistance being given to them by the Company. It has hitherto been assumed by experts that the sand filter, carefully and properly managed, yields a germ-free, hygienically perfect filtrate. If this theory were thoroughly sound, investigations of the character of those here recorded would have been useless, but it soon became evident that complete experiments touching the fate of pathogenic micro-organisms passing through the sand filter had not hitherto been attempted. It was manifestly out of the question to make a trial of the filter-basins themselves, as even if it were possible to procure the large stock of bacteria needed for the experiments, the danger of infecting such vast quantities of water, and the need of carrying out observations over so wide an area, would present insurmountable difficulties. It was therefore decided to employ small sections of the actual filter-beds, the apparatus being explained by reference to a diagram. Two tubs were used, each 2·1 metres (6·7 feet) high and 0·75 metre (2·5 feet) in mean diameter, at whose base was a sieve-like collecting channel. The filtering material was disposed in these tubs in the same thicknesses as in the actual section of the beds; viz., 100 millimetres (3·9 inches) of pebbles of the size of hazel-nuts; 80 millimetres (3·1 inches) of coarse gravel; 100 millimetres (3·9 inches) of fine gravel, and 600 millimetres (2 feet nearly) of fine sand. The surface of this sand was about 1·2 metre (4 feet) below the top of the vessel, which was provided with an overflow-pipe.

The outlet-pipe from the filters was curved upwards to above the level of the sand, and the inlet-pipe was adjusted to supply the water at any given rate. It was thus possible to work the filters at the required speed, and to avoid all disturbance of the contents. Having completed all these preparations, and formed two distinct filters, the Authors were enabled to commence their observations, and they deemed it advisable to study, in the first instance, the behaviour of a bacillus of a non-dangerous character and of strongly marked features, and for this purpose the bacillus violaceous was selected. It was cultivated in very dilute nutritive bouillon, so as to render it impossible for the bacteria, when they were exposed to the still further dilution in the filter, to find the requisite supplies of food-stuff. This liquid, which had a pale blueish tint, was added every six hours to the contents of the unfiltered-water reservoir, in quantities of about 100 cubic centimetres at a time. Samples were taken daily for bacteriological examination, both of the unfiltered and of the filtered liquids, and they were cultivated on gelatin plates in the usual way. The filters were worked, the one at the rate of 300 millimetres (11·8 inches), the other at the rate of 100 millimetres per hour. The results are set forth in tabulated form, and prove that, throughout the whole period of observation, the bacteria passed through the filter, the numbers being in general accordance with the rate of filtration. About three times as many colonies were formed in the former filtrate as there were in the latter. When the speed of filtration was reduced in the second filter to 50 millimetres per hour, the relative abundance of the colonies of blue bacteria was about as 6 to 1. The proportion of the blue bacteria in the unfiltered water to those in the filtrate was, roughly speaking, 1000 to 1. The slower rate of filtration produced, unquestionably, the better results. Similar experiments with cholera and typhoid fever bacteria gave corresponding results, which are set forth in Tables, and the Authors conclude that the sand filter is not a germ-proof apparatus, and is incapable of retaining the spores of the ordinary water-bacteria, as also those of a pathogenic character. The numbers of germs passing through the filter are in proportion to those in the unfiltered liquid, and in accordance with the speed of filtration. Both at the beginning and at the end of each periodic use of the filter, there is an interval of danger when the germs pass through the beds in greater abundance.

G. R. R.

Examination into the Utility of the Chamberland-Pasteur Pressureless Filter. By Dr. Kübler.

(Zeitschrift für Hygiene, 1890, p. 48.)

Attention is called to the need of a domestic filter capable of supplying a germ-free filtrate. The problem of constructing such a filter, with large yield and working without the pressure obtained from the water-mains, was stated to have been solved a few years ago by Messrs. Chamberland and Pasteur, whose porcelain cylinders were said to produce a filtrate free from bacteria. As the result of certain investigations conducted by Mr. Johnstone, of Sydney, at the instance of Dr. C. Fränkel, these pretensions were called in question, but the enquiry was not completed. The Author, therefore, undertook a fresh series of experiments, with a new filter obtained from the central establishment in Paris. The investigations were chiefly directed to ascertain whether the filter was capable of yielding a germ-free filtrate. The water employed for testing was that drawn from the mains of the Berlin waterworks, which, though originally containing a comparatively small number of bacteria, rapidly gained in the number of germs when retained in the reservoir. Four sets of tests were undertaken, under conditions and precautions set forth by the Author; the general results proved that the filter in question, in spite of the most careful provisions for the exclusion of impurities, was only capable of supplying a sterile filtrate for a short period (four days at the outside). The four series of tests are arranged in a tabulated form, showing the numbers of germs in ½ cubic centimetre, or in 3 drops of the unfiltered water and of the filtrate. The results obtained under the various trifling differences in the mode of using the filter were in all cases quite uniform; the filtrate being at first sterile, and then, after the lapse of three days on an average, a few colonies of the extraordinarily-active and most prolific fluorescent water-bacillus made their appearance. These were followed, two days later, by bacteria in great variety. The bacteria seemed, in fact, to grow through the pores of the filter, and thus to reach the filtrate.

G. R. R.

On the Passage of the Spores of Fungi and of Bacteria through Cloth used for Air-Filters. By Dr. Karl Möller.

(Zeitschrift für Hygiene, vol. vii., 1889, p. 379.)

The Author combats the conclusions of Dr. Petri[1] on the above subject, and, as a member of the firm engaged in the production of air-filters, and as the first who undertook to filter air upon a commercial scale for industrial purposes, he points out certain misstatements and erroneous deductions.

Air-filters are of two kinds; and for "germ-proof filters" he employs an ante-filter and ten layers of a specially thick, closely woven, and very much roughened material; for "dust-proof filters," only one thickness of a much less closely-woven fabric is used. Filters of the latter kind, though capable of excluding very large proportions of germs, are obviously not germ-proof. By the Author's arrangement of the filter in the form of a series of pockets, the cloth moreover is used in a direction very oblique to the air-current, forming an angle with it of from 3° to 5°, whereas Dr. Petri tested the cloth at right-angles to the air-current. By

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[1] Minutes of Proceedings, vol. xcvii., p. 460.

reference to enlarged sections of the fabric, the vast difference in the degree of permeability due to this change in the direction of the movement of germs is explained. It is shown also that Dr. Petri considerably strained the filter-cloth by subjecting it to the passage of abnormal volumes of air. Moreover, the Author asserts that a woolly surface is one capable of entangling large numbers of germs, and that Dr. Petri actually neglected the obvious precaution of sterilizing his cloth before the commencement of his experiments. He thus, doubtless, was led to regard a vast number of germs as having passed through the cloth, which, as a matter of fact, had been simply blown off its surface by the air-current. The experiments of Dr. Petri are discussed in detail, and certain of them, for various reasons, are shown to be untrustworthy.

G. R. R.

On the Disinfection of Latrines by means of Lime.

By Dr. E. Pfuhl, of Berlin.

(Zeitschrift für Hygiene, vol. vii., 1889, p. 363.)

Having by previous experiments[1] demonstrated that the excreta of typhoid and cholera patients could be disinfected by means of relatively small quantities of milk of lime, the Author resolved to investigate further whether the experience gained in the laboratory could be used in actual practice for the disinfection of fecal matters in tubs, cesspools, and night-stools. Lime can be procured on a commercial scale in such a pure state, as only to contain 1 per cent. of foreign matters, as has been found in the case of Wiesbaden, where from 2,000 to 3,000 kilograms of lime are used every twenty-four hours for the treatment of the sewage-water. The precautions to be taken in slaking and preparing the milk of lime are described. It is advisable to use double the quantity of water theoretically needed, viz., 60 parts of water to 100 parts of quicklime. It may be assumed with sufficient accuracy that 1 litre of slaked lime weighs ½ kilogram; and in preparing a mixture of lime for use as a disinfectant, 1 litre of slaked lime is to be mixed with 4 litres of water. To test the action of the lime on the fecal matters, the Author advocates the use of red litmus paper, coloured blue to various shades by solutions of lime of different known strengths. For cesspool-matters, as the result of a series of experiments on a cesspit of large size, details of which are given, as also full particulars of trials carried out on tubs used daily by soldiers in a barracks, the Author recommends the use of from 1 to 1½ litre of slaked lime to each 100 litres of excreta contributed daily, the larger quantity being that advocated for tubs or pails. As the results of actual measurement, the daily increment of cesspool contents was found

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[1] Minutes of Proceedings Inst. C.E., vol. xcvii. p. 459.

to be 400 cubic centimetres per head. The disinfection can best be effected when carried out daily. No reliance can be placed on any hand-mixing of the excreta with the lime. There is, therefore, no other course than to depend upon automatic admixture, or to arrange for some system of mechanical stirring of the cesspool contents, such as is accomplished by the apparatus of Thiriart, which is described.

G. R. R.

The Disinfecting Action of Chloride of Lime.

By Dr. Franz Nissen.

(Zeitschrift für Hygiene, 1890, p. 62.)

The first bacteriological tests of the action of chloride of lime were given in Koch's work "On Disinfection," and it was shown therein that anthrax spores, dried on to silk threads, were destroyed by a five days' exposure to the action of a 5 per cent. solution of the salt. Subsequently Sternberg and Jaeger have published the results of observations which differ in certain indicated particulars from those of Koch, and it therefore appeared advisable to undertake a fresh enquiry, which the Author has carried out under the guidance of Dr. Koch. Samples of chloride of lime were procured from various dealers, and in all cases the material used was taken from the bottom of the jar or cask. Chloride of lime consists of a mixture of hydrate of lime, calcium chloride, and calcium hypochlorite. The contents in hypochlorous acid, which varies widely, was ascertained in most cases by titration. The disinfecting action was tested by exposing the bacilli of typhoid fever, Asiatic cholera, anthrax, and two other species, immersed in alkaline bouillon, containing 1 per cent. of pepton and 0·5 per cent. of common salt, to equal volumes of the solution of chloride of lime. The liquids were well shaken, and samples, withdrawn after the lapse of one, five, ten, fifteen, and twenty minutes, and at longer intervals, were submitted to pure cultivation. The results of the observations are set forth in a series of tables, as also those of a further set of experiments directed to test the deadening powers, as respects the development of micro-organisms, of the chloride solution. In this latter respect, the influence of calcium chloride is insignificant. A third series of experiments was carried out with polluted liquids and human excreta, and from these it was ascertained that a 5 per cent. solution was capable of destroying the germs present in diarrhœtic fæces within less than ten minutes. From the first set of tests it was shown that the bacilli of cholera, typhoid fever, and anthrax[1] were destroyed by a solution containing not less than

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[1] In a note appended by the Author he states that some anthrax spores recently received, with such high powers of endurance as to be capable of resisting a four hours' exposure to a 0·1 per cent. solution of corrosive sublimate, had succumbed in 4½ hours to a 5 per cent. solution of chloride of lime.

0·12 per cent. of calcium chloride in one minute. The germs of staphylococcus and streptococcus were rendered incapable of further development by exposure for one minute to a 0·2 per cent. solution of the chloride in bouillon.

G. R. R.

Micro-Organisms in a Spring from the Cretaceous Formation of Havre. By L. Thoinot.

(Annales de l'Institut Pasteur, 1889, p. 145; Chemisches Centralblatt, 1890, vol. i., p. 48.)

The Author undertook, in conjunction with Mr. Brouardel, an examination into the causes of an epidemic of typhus at Havre, and came to the conclusion that the outbreak was due to pollution of the spring at Catillon. Towards the end of the years 1886 and 1887, the cultivated plateau of Gainneville, which covers the water-yielding layers of Catillon, had been manured for the first time with the contents of the refuse-tubs of Havre. The formation is chalk, under which lies a layer of clay, and upon the outcrop of the latter the water appears as a spring. The investigations undertaken by the Author show that a chalk-spring under these conditions may be polluted at its source. Even a thickness of 20 to 25 metres (22 to 27 yards) of chalk, as in the case of the Sauvic spring, does not offer sufficient security against pollution, because contaminating substances may pass through the fissures of the chalk. Under such conditions, the Author considers it dangerous to use excrementitious substances for manuring fields in the neighbourhood of towns.

W. F. R.

The Action of Hydrogen Peroxide upon Infusoria.

By J. Paneth.

(Chemisches Centralblatt, vol. i., 1890, p. 174.)

The infusoria with which these experiments were made were produced by inoculating a hay infusion with stagnant water and mud. The liquid thus obtained contained at least six different varieties of infusoria. The hydrogen peroxide was used in the form of a carefully neutralized solution of known strength. When the solution contained one part of hydrogen peroxide in ten thousand parts of water all ciliate infusoria were invariably killed in one-quarter to half an hour. With a dilution of one in twenty thousand part of the organisms were destroyed, but some survived. The hydrogen peroxide was decomposed, either through the substances dissolved in the infusion or more probably by a catalytic action of the organisms. Hydrogen peroxide is therefore a violent poison for some forms of animal protoplasm. The Author concludes from his experiments that the oxidising effect of such infusoria cannot be due to the presence of hydrogen peroxide in their cells, and from other experiments he is of opinion that they do not contain active oxygen to any considerable amount.

W. F. R.

The Destruction of Artesian-Well Pipes. By STEFAN FISCHER.

(Wochenschrift des österreichischen Ingenieur- und Architecten-Vereines, 1889, p. 355.)

The remarks in this Paper are based on the Author's personal observation and examination of a large number of wells in the plains of the Po, in North Italy, and it is stated that at least five hundred of such wells are there to be met with at varying depths, extending even down to 2,230 feet. The Author's first experience was with wells in the Ferrara district, where the iron pipes were from 8½ to 11 inches in diameter, and about ½ inch thick. One of these wells was sunk about 360 feet below sea-level, and no fresh water was found; but, when the pipes were drawn up six months later, they were so badly eaten away or corroded in some places as to leave but a thin outer skin, though the cross-section showed the quality of the iron to be hard and good. A similar experience was gained last spring in the Volta valley with seven Norton tube wells which had been sunk, in 1884, to an average depth of 122 feet, and therefore much below sea-level. The exterior diameter of the tube was 2⅛ inches, and thickness about ⅕ inch, the bottom of the lowest tube was perforated as a sucker for a length of about 4 feet, and surrounded by a brass webbing. Last year it was noticed that the yield of water had diminished, and the quality deteriorated, and when pumped violently large grains of sand and gravel were brought up, showing that the tube must have been eaten through somewhere. The tubes from three of these wells were accordingly taken up, and showed in some places a small groove or channel extending for about one-tenth of the interior circumference, while the remainder was perfectly sound and smooth. In some of the tubes there was also an irregular line of slits and holes arranged longitudinally, which perforations both in profile and longitudinal section had a circular or oval form, while between the perforations the thickness of the pipe was preserved entire; and this singular fact was also observed, viz., that the holes in the suckers were hardly affected, and the brass webbing not at all.

Similar results have been obtained in other artesian wells, especially in and around Venice, sunk to depths varying from 160 to 230 feet, and it is stated that wells sunk in Romagna, in 1859, have nearly all been destroyed, and that in Cervia (on the sea-coast between Ravenna and Rimini) the wells yielded water abundantly until

1884, and then gradually dried up. New wells have, however, since been sunk and the original abundant supply restored, but at great trouble and expense. The Modanese wells—that is the almost innumerable quantity of tube wells constructed after one type in the plain at the foot of the Apennines between Castelfranco and Reggio d'Emilia—appear to be quite free from corrosion: these, however, are generally of small depth, and almost without exception do not reach sea-level, and they derive their water from gravelly streams which are almost entirely free from iron. The Author attributes the destruction of the pipes to two causes—one mechanical and the other chemical—that is to say, the water ascending in the pipes brings with it sandy or gravelly particles, which by friction wear away the face or skin, and, this having been done, the water, being endowed with the capacity of setting free the iron in the pipe, slowly dissolves chemically the interior core, and finally attacks and perforates the outer face also. The fact of this corrosion not taking place all round the tube is explained by assuming a slight obliquity in its direction; the particles of sand will therefore gravitate to the lower side only, and there gradually grind down the face, and thus prepare it for the chemical action of the water on the interior mass. This partial corrosion of the pipe is therefore not due to defects in construction, but solely to the combined action under the above conditions of the mechanical and chemical forces above mentioned. To prevent the destruction of artesian wells, wooden pipes have been used in the Gallara district, and copper, glass, paper, &c., are also suggested; but objections are found to each, and the Author concludes by saying that the desired solution of the question can only be obtained by long-continued experiment, and that whoever does solve it will render great service, not only to the dwellers in the plains of the Po, but to all who live in similarly inundated lowlands.

W. H. E.

Contributions to Theory of the Indicator. By Dr. A. SLABY.

(Zeitschrift des Vereines deutscher Ingenieure, 1889, p. 789.)

Dr. Slaby first directs his attention to the deflection of indicator springs under varying loads. The indicators were fixed in position, and the springs deflected by pressures exerted on the indicator pistons, which were suitably measured, and the deflections, as given by the pencil, observed. When required the springs were heated by a current of steam.

Three circumstances were found to interfere with the maintenance of a constant ratio between the deflection of the springs so measured and the applied pressures:—(1) Want of proportionality in the scale of the springs; (2) different deflections under the same pressure when the load is increasing and when decreasing; (3) different deflections under the same load at different temperatures.

When the indicators were fitted with a correct parallel motion, the first cause of difference disappeared, and Dr. Slaby found a difference in the deflection of the springs of 3 per cent., with the same pressure on the springs between putting on and taking off the load. As friction was got rid of by tapping, this was due to some elastic effect in the spring itself. The latter deflection was always the greater. The difference in the deflection of the springs with the same load at the ordinary temperature and at the boiling-point was 2 to 3 per cent.

To get rid of these difficulties and to simplify the method of assigning the proper modulus of stiffness to indicator-springs he introduces the dynamical method. Taking the formula for the time of vibration of a spring as

$$T = 2\pi\sqrt{\frac{h}{g}},$$

where *h* is the deflection due to the equivalent weight of the moving parts collected at the piston of the indicator.

T was found by experiment from diagrams into which vibrations entered freely; in this way the stiffness of the spring was calculated, and was found to agree within 0·1 per cent. with the stiffness as taken from the mean of the deflection on loading and unloading the spring when heated.

From this he concluded that to assign proper moduli of stiffness to indicator-springs it is only necessary, after having carefully ascertained the stiffness of one spring by experiment, to take diagrams from the same engine at the same time with the tested spring and compare the areas of the diagrams, so deducing the stiffness of the second spring.

A. W. B.

Mechanism of Magnified Rectilinear Motion applied to the Indicator. By W. Hartmann.

(Zeitschrift des Vereines deutscher Ingenieure, 1890, p. 26.)

Mr. Hartmann investigates the first cause of error pointed out by Dr. Slaby, viz., want of proportionality in the scale of the indicator due to the magnifying mechanism. He reviews the various methods in vogue for giving the pencil a magnified rectilinear motion of that of the piston, and shows the error in each form. He proves that the pantograph design of parallel motion, with the three characteristic points in the same straight line, gives an absolutely true magnification of the motion of the indicator piston, and refers to a number of modifications of this form more or less accurate.

A. W. B.

A Compressed-Air System of Forced Draught. By G. F. Kutz.

(Journal of the American Society of Naval Engineers, 1889, p. 330.)

A small steam-launch was constructed in 1887, at the Mare Island navy-yard, for service in Alaskan waters. The engine is compound, having cylinders 4 inches and 7 inches in diameter, with a stroke of 6 inches. The boiler is of the "low cylindrical" or direct horizontal tubular type, having 2·30 square feet of grate-area. To furnish the necessary draught, a system of forced draught was designed by Mr. Klotz; according to which a small air-compressor, having a 4-inch cylinder—of the same diameter as the first cylinder of the engine—having a composition valve-seat screwed on to each end with a hard india-rubber valve, the piston being driven from the first crosshead. The compressed air was conducted in an iron pipe to the front of the ash-pan of the boiler, where it was delivered through a rectangular slot in the pipe into an elongated nozzle forming part of the ashpan-door; the pressure being regulated by means of a wedge-valve, by which the degree of opening of the slot could be varied through which air was drawn by induction. By the results of several trials, it was shown that with a pressure of air of from 1½ lb. to 2 lbs. per square inch, the consumption of good bituminous coal was about 30 lbs. per square foot of fire-grate per hour.

The draught on this system is largely an induced' draught. In the present case, the quantity of compressed air delivered was not more than 10 per cent. of the air chemically required for complete combustion; the remaining 90 per cent. being supplied by induction.

The system was tried on the steam launch of the "Iroquois," 28 feet 2½ inches long. The boiler was like that already noticed. The shell was 41 inches in diameter, 36½ inches long; the furnace-tube was 23½ inches in diameter, with a fire-grate 17 inches long. There were one hundred and sixty-one flue-tubes, 1½ inch in diameter outside, 18 inches long. The grate-area was 2·78 square feet, and there was 90 square feet of heating surface. The smoke-pipe was 8 inches in diameter, 6 feet high above the level of the grate. The compressing cylinder, 4⅛ inches in diameter, with 6 inches of stroke, was driven from the crosshead of the first cylinder. The opening for admission of air to the ash-pit was 1⅛ inch by 11 inches wide. The results of comparative trials, with the natural draught and induced draught, using anthracite, were as follows:—

	Natural Draught.	Induced Draught.
Duration of trial, hours	2	2
Steam pressure in the boiler, pounds per square inch	50	60
Vacuum in condenser, inches	24	24
Revolutions of engine per minute	165·1	288·5
Temperature of feed-water	78°	93°
Temperature of water overboard	64°	67°
Coal consumed per hour, pounds	15	35
Water evaporated per hour	88·8	275·5

It is stated that, with natural draught, the speed was barely 3 knots per hour; whilst with the air-blast, 6 knots were made easily.

It is stated that the induced-draught system has been applied to the Cunard steamship "Servia," as patented by Mr. Anderson, of Glasgow. He does not employ ash-pit doors. The jet and induction nozzles have the form of hollow truncated cones, and are on the pipe which conveys the compressed air. The greater part of the induced current enters the hollow cones. On the "Servia" the air-compressors are driven by special compound engines with an accumulator.

D. K. C.

On the Influence of Temperature of Air supplied under the Fire-grates of Steam-Boilers. By — POUPARDIN.

(Bulletin de la Société Industrielle de Mulhouse, December 1889, p. 615.)

Messrs. Meunier and Scheurer-Kestner had obtained about 7 per cent. greater evaporative efficiency in summer than in winter, from the same boilers, under like conditions—an excess which had been explained by the difference of loss by radiation and conduction. But Mr. Poupardin, surmising that the gain might be due in some degree also to the greater temperature of the air in summer, made comparative trials with six new steam-boilers at the works of Messrs. Schlumberger, Sons, and Co., at Mer Rouge. An apparatus, consisting of a series of cast-iron pipes, was placed vertically in the flue-way towards the chimney. The upper ends were open to the air, the lower ends opened into a chamber, from which the heated air was conducted to the front of the boilers. The smoke circulated amongst the pipes as in Green's economiser. In May, 1889, two series of trials were made with two groups of three boilers each, working one week with the heated air, and the next week with cold air. The following were the several efficiencies:—

First trials: Ronchamp coal.

	Water per lb. of Coal.	Water per lb. of Volatile Elements.
With heated air (128° Fahrenheit)	7·77 lbs.	8·95 lbs.
With cold air (69·8° Fahrenheit)	7·33 "	8·63 "
Difference in favour of heated air	0·44 "	0·32 "

Second trials: same coal; three other boilers.

With heated air (120·4° Fahrenheit)	8·70 lbs.	10·08 lbs.
With cold air (75·2° Fahrenheit)	8·09 "	9·34 "
Difference in favour of heated air	0·61 "	0·64 "

These results show economies in favour of heating the air of 6 per cent. and 7½ per cent. The respective average pressures of steam were, 4·25 and 4·30 atmospheres in the first trials, and 4·3 and 4·26 atmospheres in the second trials. The respective quantities of coal consumed were, in the first trials, 48,180 lbs. and 45,540 lbs.; in the second, 44,660 lbs. and 48,180 lbs.

Mr. Poupardin believes that the gain in efficiency is due chiefly to the better combustion of the gases with heated air. It was observed that with heated air, the flames were much shorter and whiter, and that there was notably less smoke from the chimney.

D. K. C.

Calorimetric Researches on the Cycle of the Gas-Engine.
By Dr. A. Slaby.

(Verhandlungen des Vereins zur Beförderung des Gewerbfleisses, 1890, p. 23.)

In this Paper the Author describes his experiments upon the heating-value of coal-gas, and states that the heating-power is liable to great variations, amounting in a few hours to as much as 8 per cent. In the forenoon the variations are less and reach only to 2 per cent.

For the calorimetric examination of a gas-engine it is absolutely necessary to determine the heating-value by actual experiment, as mere analysis is insufficient. The heating-value of the heavy hydro-carbons, contained as essential constituents in lighting-gas, vary from 13,000 to 27,000 calories (1,461 English heat-units per cubic foot) per cubic metre (3,034 English heat-units per cubic foot).

Trustworthy results may be obtained by the combination of the analytical method with the method of measuring the specific gravity, which latter method rests upon the fact that the heating-value of those heavy hydro-carbons is connected with the density by a simple law.

He states that Schilling's apparatus, according to Bunsen's description, only gives reliable results if considerable time is allowed and certain precautions taken.

The whole Paper emphasizes the need of exact knowledge of the heating-value of the gas used in engines while testing for the determination of the heat-distribution in the gas-engine, and the Author states that Witz's results are erroneous because he neglected to observe the variation to which he referred.

D. C.

Test of an Otto Gas-Engine. By H. W. Spangler.

(The Journal of the Franklin Institute, February 1890, p. 115.)

This article is an abstract of a test made in January 1889, by Messrs. Kidwell and Keller, to determine the distribution of the heat developed by burning the gas. The gas-engine tested was of 7 HP. nominal, of the Otto type. The working capacit cylinder was 0·2594 cubic foot, with 0·1796 cubic foot ance space, or 69 per cent. of the working capacity. The was water-jacketed.

Duration of test	3 hrs. 10 mi
Temperature of gas supplied	62·2° Fahr
„ exhaust	774·28° „
„ entering water	50·43° „
„ exit water	89·19° „
Pressure of gas, inches of water	3·06
Barometer, reduced to pounds per square inch	14·85
Total gas used, cubic feet	344·4
Gas for ignition, cubic feet	9·625
Average number of revolutions per minute	161·6
Explosions missed per minute	6·83

The computations show that the effective mean press 59 lbs. per square inch; or (59 × 144) per square foo volume of the stroke was 0·2594 cubic foot; the w explosion was (59 × 144 × 0·2594 =) 2,203·8 foot-l plosions per minute $\left(\frac{161\cdot6}{2} - 6\cdot83 =\right)$ 73·97; hors $\left(\frac{73\cdot97 \times 59 \times 144 \times 0\cdot2594}{33{,}000} =\right)$ 4·939 I. HP.

The work per explosion (2,203·8 foot-lbs.) ÷ 772 = 2·8 units transformed into work at each explosion. By the jacke 461·92 heat-units were carried away per minute; or (46 73·97 =) 6·24 heat-units so removed per explosion. T carried off by the exhaust was 3·405 units. The distrib the heat stands thus :—

	Units.	Per cent. Heat recei
Heat converted into work per explosion	2·85	or 22·91
Heat taken by jacket water	6·24	„ 50·16
Heat carried off by exhaust	3·40	„ 27·93
Total heat accounted for	12·49	100·4
Total heat received	12·44	

The composition of the gas was as follows :—

	By Volume.	By Weight.
CO_2	0·50 per cent.	1·923 per ce
C_2H_4	4·32 „	10·520 „
O	1·00 „	2·797 „
CO	6·33 „	15·419 „
CH_4	27·18 „	38·042 „
H	51·57 „	9·021 „
N	9·06 „	22·273 „
	99·96 „	99·995 „

D.

On the Light- and Heat-Radiation of Burning Gases.

By Dr. W. H. Julius.

(Verhandlungen des Vereins zur Beförderung des Gewerbfleisses, 1889, p. 357.)

The Author first mentions the theories of combustion held by Stahl, Lavoisier and Berzelius, proceeds to discuss the phenomena in view of more recent researches, and concludes with an account of the results obtained in his own experiments. He distinguishes between explosion and combustion by flame, and he confines his consideration more particularly to flame, referring to explosion only in so far as is necessary to elucidate the question of flame. Frankland's experiments led to the first important modifications of Davy's theory of luminosity by proving that many flames were powerfully luminous without having present any solid particles as assumed by Davy, and the most non-luminous flames could be made luminous by increasing the pressure at which they burned.

The theories of many other experimenters were discussed, and then the Author describes Langley's Bolometer, as arranged by him, together with the necessary optical and electrical apparatus required in his experiments upon the radiating-power of flames. With regard to the heat-spectra of flames, he studied separately the flames of the Bunsen lamp, hydrogen and carbonic oxide, and elicited the interesting fact that while the Bunsen flame heat-spectrum shows two positions of maximum radiation, the carbonic-oxide spectrum only shows one maximum point, as also the hydrogen flame. With regard to luminous flames he considers that the heat and light maxima nearly coincide. Similar experiments were made with lamps burning carbon bisulphide, sulphur vapour and sulphuretted hydrogen. In the spectrum from the carbon-bisulphide flame the Author expected to find two maximum points, but instead he found four. This he explained to some extent by reason of the formation of carbon oxysulphide in the flame as a by-product, which was proved by chemical tests to be the fact.

The flames of hydrogen in chlorine and bromine were also tested, and also the cyanogen flame in air, which latter was very similar to the carbonic-oxide flame in air. Phosphoretted hydrogen was also burned, and the radiated heat from many solid bodies examined.

The Paper has many illustrations of the apparatus used in the investigations, together with curves representing the distribution of heat in the various spectra, while numerous tables of results are given. All the details of the experiments are entered into with great minuteness, and the Paper concludes with a discussion of the explanation of the phenomena, in which the controversy between Siemens and others as to the radiating-power of flame is referred to, but no very definite conclusions arrived at.

D. C.

Three-Cylinder Petroleum-Engine. By L. Müller.

(Le Génie Civil, vol. xvi. p. 271, 9 Figs.)

Mr. Lalbin has just completed a new engine which works by the combustion of petroleum-gas, and has been tested lately at Nantes upon a boat carrying twenty people; the speed of the boat reached 6½ knots per hour. One of the great advantages of this type of engine is that it is exceptionally light, so that the size which develops ½ HP., and can be used for a tricycle, only weighs 88 lbs., while that of 1 HP. weighs 132 lbs., and the one used in the trial-trip, which was of 5 HP., weighs only 440 lbs. In elevation it occupies an area 1 foot 11 inches diameter, including the exhaust-pipe, and the fly-wheel is only 25 inches in diameter, and weighs 110 lbs. The exhaust is led into the water, and the cylinders are cooled by a small automatic pump. The petroleum-gas is held in an iron tank of 11 gallons capacity, provided with a screw-joint by which it is connected to the mixing-chamber, a kind of box fitted with wicks, placed under the deck, while the petroleum-tank is placed under one of the seats. The air drawn in by the movement of the pistons travels through the mixing-chamber, and takes up from the soaked wicks a supply of petroleum-vapour which can be regulated by means of a valve worked by hand. A Leclanché battery produces the spark required to explode the combustible mixture. The amount of petroleum used is about 0·11 of a gallon per HP. per hour, so that with a petroleum-tank of 11 gallons capacity, and an engine developing 5 HP., the boat would run for about twenty hours. The three cylinders are arranged in a vertical plane, with their axis radial to the propeller shaft, and at 120° from one another. The pistons are of trunk form, and the three connecting-rods act upon a common crank, giving at all times an almost constant thrust upon it, so that the fly-wheel does not need to be heavy. The work upon each piston, besides forcing it out, causes the indrawing of the charge for the second, and the compression of the charge for the third. The spark is produced by a secondary current, induced by a primary current from a Leclanché battery. The disk, carrying the cams which work the different valves of each cylinder, revolves in an opposite direction to the crank-shaft, and at half the speed; this method causes an explosion to take place in every second cylinder, as it comes round with the greatest regularity. The diameter of the pistons in the 5-HP. engine is 5·07 inches, and the stroke 5·26 inches; the total length of the engine is only 2 feet 7¼ inches, and it is reversed by means of a hand-lever which moves the cam disk. The exploding mixture is regulated according to the speed required, either to give the maximum power at 400 revolutions per minute, or the minimum at 100 revolutions per minute.

E. R. D.

Notes on the Erosive Power of Compressed Gases.

By — Daubrée.

(Mémorial de l'Artillerie de la Marine, vol. ii. 1889, p. 245.)

The Author attributes the erosive action of powder to three distinct causes. First, there is the physical action, caused by the elevation of the temperature of the metal which is in contact with the superheated gases. It is this elevation of temperature which twists and contorts thin layers of the steel into tortuous forms. Secondly, there is the chemical action due to the combination of these small particles with the elements of which the gases are composed. The most noteworthy result of this combination is the production of iron pyrites. Thirdly, there is the mechanical action due to the impact of the gases against the walls which enclose them.

With dynamite, nitro-glycerine, and gun-cotton this mechanical action is much the most marked, while the calorific and chemical effects of explosion are not always perceptible. In comparing the effects produced by the explosion of these agents with that of gunpowder, the much greater erosive effect produced by the former the Author attributes to the rapid increase of the erosive power of gases as their pressure and temperature rise. He attributes the pitting and distress in the surface of the metal in contact with the gases to the fact that these are so highly compressed at the instant of explosion as to act like solid bodies.

D. S. C.

On the Technical Value and Preparation of Magnesia.

(Annalen für Gewerbe und Bauwesen, vol. xxxv. 1889, p. 139.)

Magnesia, formerly chiefly valued on account of its medicinal properties, has recently risen into great commercial importance, owing to its infusibility and its employment as a lining for convertors used in the basic process of steel manufacture. Caron, whose process was in the first instance followed, used calcined magnesite. This was made up with $\frac{1}{6}$ of its weight of tender-burned magnesia, and from 10 to 15 per cent. of water, into a plastic state; it was then compressed into bricks in iron moulds, and burned at a dull red heat. Professor Ehrenwerth has pointed out that, if the refractory properties of the magnesia are to be evoked to the full, it is of the utmost importance that the whole of the magnesia should be dead-burned; the process, moreover, being carried so far as not only to expel the whole of the carbonic acid, but also to cause the full amount of shrinkage which this material is capable of attaining. This extreme amount of calcination is very difficult to effect, owing to the tendency of the magnesite to fly into splinters, and to drop to pieces when subsequently touched, and in consequence of its being such a bad conductor of heat the stone is very hard to burn in large pieces.

Recently dolomite, which is a double carbonate of lime and magnesia, has been used instead of magnesite. In order to prepare this material there are two processes before the public; that of Closson, and that of Scheibler. Under the former plan, the calcined dolomite is mixed with chloride of magnesium, the chlorine in which separates from the magnesia and combines with the lime, yielding a soluble calcic chloride which can readily be washed out, leaving behind the insoluble magnesia. Under the process of Scheibler, the calcined dolomite is treated with dissolved sugar, leading to the formation of sugar of lime, and depositing the magnesia. The solution of sugar of lime is then exposed to carbonic acid gas, which separates the lime as a carbonate, leaving the sugar ready for re-use. Both these systems of producing magnesia have the advantage of relative cheapness in their favour, owing to the low price of dolomite. Professor Frank, of Charlottenburg, has advocated the use of magnesia as a substitute for plaster of Paris for casts, and Grundmann has recently shown the advantage of employing a mixture of magnesia and powdered marble for this purpose. The Author states that he has found, following the direction given by Hirzel, that a mixture of benzole and magnesia is the very best possible substance for the removal of grease from drawings, or from any other material.

G. R. R.

The Occurrence and Extraction of Ozokerite in Galicia.

By J. SHOTSKY.

(Allgemeine österreichische Chemiker- und Techniker-Zeitung, 1889, pp. 614 and 651.)

The most important deposit of ozokerite is near Borislaw, where it occurs in a marl containing salt. The wax is found in irregular lumps, sometimes of great size, or in layers which frequently die out completely. The neighbouring rock consists of clay-slate, marl and sandstone.

The centre of the basin is richest in wax; in some cases masses of such extent have been tapped that the miners have hardly had time to escape before the workings were filled with the plastic mineral. Such a deposit was recently found in the deepest shaft at Borislaw at a depth of 208 metres (227 yards). In general, however, the yield of wax varies at from 2 to 8 per cent. of the mineral extracted. Ozokerite was first found in this district in 1854 by Doms, who was in search of petroleum with which much of the ground is saturated. At first it was regarded as an unwelcome companion to the petroleum, as it frequently caused the timbering of the shafts to collapse. It was not until about twenty years later that this substance began to attain commercial importance, a method having then been discovered of producing from it a substance resembling beeswax and named ceresin.

In 1865 ozokerite, which had previously been regarded as a crown mineral, was declared free, and the consequence was that a number of shafts were sunk in the district, and much speculation ensued. The land being parcelled out in small plots, the shafts were sunk in the immediate neighbourhood of each other, and much waste and danger ensued. In 1886 the present law was passed, according to which the right of mining for ozokerite may be separated from the ownership of the land. The extraction is now carried out under official supervision.

In nearly every case the mineral is raised through vertical shafts or pits over which a wooden roof is erected. The section of the shafts in the first instance is 3 to 4 square metres (32 square feet to 43 square feet); but when the ozokerite formation is reached, an inner shaft 1 metre square (10·76 square feet) is formed of timber, and the space between this and the timbering of the larger shaft is filled with a rich clay. This construction is adopted to exclude the surface-water, which is kept down by hand-pumps during sinking. From the bottom of the shafts levels are driven into the ozokerite ground, the richer portions being raised and the refuse used to fill up the old workings. The softer parts of the marl are dislodged by means of pick or wedge; but where the rock is hard, and the permission of the mining authorities can be obtained, dynamite is used. The mineral is raised by hand in skips or tubs holding 40 to 50 kilograms (88 to 110 lbs.). Hand-ventilators are used for the purpose of ventilation, but explosions of gas are not uncommon, especially after Sundays and holidays. Fatal accidents are, however, rare. Safety-lamps are used in all the mines. The timbering of the shafts requires constant renewal and repairs; in some cases it is almost impossible to keep the shafts perpendicular.

The water is usually raised in tubs, and much difficulty is experienced in getting rid of it after it reaches the surface, on account of the numerous shafts and the broken nature of the ground. The mineral, when it leaves the tubs, is sorted by hand. The waste rock is picked out and tipped to spoil, lumps of ozokerite are specially selected, and the remainder of the rock, containing fragments of wax, is tipped into tanks full of water. On being well stirred most of the wax rises to the surface and is skimmed off. The residue still contains from 2 to 3 per cent. of wax. The quantity of waste mineral being considerable, and the distance between the shafts small, a special railway has been built to remove the residues from the immediate neighbourhood of the mines.

Only one attempt has been made to mine on a large scale for ozokerite. In this case a circular shaft, 2 metres (6 feet 7 inches) in diameter and lined with iron tubbing, was sunk outside the ozokerite zone, and the deposit was reached by galleries. Trucks holding 500 kilograms (1,102 lbs.) were used, and both ventilation and pumping were done by steam-power. The operations on a large scale do not, however, seem to have been successful, the French company which carried them out having now ceased working.

The production of ozokerite in the Borislaw district amounted in 1887 to 96 per cent. of the total output in Galicia, and was valued at £152,900.

W. F. R.

On the Use of Carbon and Coke Bricks in Blast-Furnace Hearths.

By F. Burgers.

(Stahl und Eisen, vol x. p. 112.)

The maintenance of the hearth and bottom in the blast-furnace is to most smelters a troublesome and anxious task. Even in a new furnace, with the corrosive slags required by modern methods of working, the tendency is, according to the Author, for the refractory brickwork of the hearth to melt and flow like butter in the summer sun; hearths with 3 or 4 feet thickness of walls being reduced in a short time to a few inches, and necessitating the use of continuous cooling with water, which, by rendering the bricks brittle, is often attended with grave dangers from escape of molten metal through the weakened structure. This corrosive action may be well studied on the cinder-fall of the furnace, the best fire-bricks being eaten out into a gutter in an hour or two if the current of molten cinder is allowed to flow over them. These circumstances led the Author to seek for a more resisting material, and finding that the lining of a furnace when blown out was often found to be protected in the hearth by a mixture of coke-dust and graphite, cemented by lime and cinder; and also that practice showed that the best lining for the cinder-channel was formed of coke-dust and ashes, he was induced to experiment with bricks containing coal- or coke-dust, graphite, and other substances in admixture with fire-clay. The first trials were made in 1882, and the bricks made by Dr. Otto and Co., although partly defective owing to the carbon being considerably diminished in the burning, stood remarkably well against slag-corrosion. A patent was, however, refused in Germany, owing to the fact that mixtures of coke-dust and clay had been in use for a long time in the Harz lead-furnaces. In 1885, on the publication of Mr. Pourcel's Paper on the manufacture of ferro-manganese,[1] stating that at La Voulte and Tamaris the hearths and bottoms of the furnaces were built of bricks made of gas-retort carbon, containing 1 to 2 per cent. of ash,

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxi. p. 408.

mixed with tar and burnt, the Author tried finely-ground coke, with a low proportion of ash instead of retort-carbon, and obtained equally good results. The hearth of the No. 2. furnace at Gelsenkirchen was in that year rebuilt with these bricks, and has stood the wear of a large daily make up to the present time. They have also been applied in the new furnaces at the Rhenish Steel Works at Rombach, and in the lead-smelting furnaces at Mechernich. The principal advantages are the suppression of water-cooling; the maintenance of the original shape of the hearth from the beginning to the end of the period of blowing, and the prevention of furnace bears on the bottom. The hearth may also be completely isolated from the foundation, as has been done by Mr. Lürmann at Ruhrort and Rombach. Other advantages are to be found in the circumstance that carbon, even at the highest temperatures, expands but slightly, if at all, and that it is an exceedingly bad conductor of heat. The cost of these bricks is about £5 per ton. The manufacture, which is accompanied with the production of a great quantity of soot and smoke—the first experiments, according to the Author, having been comparable to lamp-black making—has been carried out at the Mechernich Works which, being surrounded by barren moors, is not liable to interference from the sanitary authorities for nuisance. Mr. F. W. Hupertz, the manager of the works, has, however, devised means for rendering the soot harmless to the works and the neighbourhood, and under his management the bricks for the furnaces mentioned above, and some others, have been produced.

H. B.

A New Form of Coal-Washing Machine. By Max Evrard.

(Bulletin de la Société de l'Industrie Minérale, vol. iii. 1889, p. 317.)

This machine is a modification of the ordinary piston- or hydraulic jigger, having an arrangement for scraping the surface and removing the top of the washed layer of material under treatment. It consists of a rectangular sieve-plate about 10 feet long and 3½ feet wide fixed on a pyramidal hutch, having a plunger box attached to one of the long sides, and a continuous opening variable by adjustable slides for the discharge of the heavier waste on the other.

The apertures in the sieve-plate vary in size, the largest being nearest to the feed end. The piston, which is circular in form, and of very much smaller area than the sieve-plate, is a wooden disk moved by an eccentric, and communicates motion to the water in the hutch by a cushion of air confined above the water in the piston-box. The eccentric is adjustable upon its shaft so as to allow a certain variation in the length of stroke of the plunger. A clack in the disk allows air to enter if a vacuum is formed below it on the return stroke by reason of the whole of the water not

being returned, as in the case of washing very fine slack
clay, which always absorbs a notable quantity of water.

The scraper-frame (*cadre à palettes*), which is th
novelty of the machine, is a harrow-like frame suspe
system of jointed rods above the sieve-plate, and receivi
from a cam acting upon the counterpoised arm of an a
which gives a slow forward and quick return motion.
which is somewhat larger than the sieve-plate, is conne
end with the slide closing the feeding-hopper, and recei
portion of material at the commencement of the strok
dropped upon the plate at the coarse end, and subjected
energetic action of the water, while the finer portions
charges brought to the surface are drawn forward by
projecting from the frame towards the discharging
length of stroke of the frame is 20 inches, so that the
the washed material is broken up six times in its passa
the 10-feet length of the machine. Usually the frame is
at such a height as to pass clear of the charge on the ret
but when the slack treated is very dusty, it is so adjus
acting on the muddy surface on the backward passage,
of the water to the hutch may be facilitated. In the
care is taken to keep a depth of from 2 to 4 inches of w
the top of the charge to prevent the suspended mud fro

The finely divided material accumulating as mud in
is discharged at intervals through a pipe at the bottom i
basins, and the clear water is pumped back to supply the
If the interior of the hutch is divided into two parts, e
separate discharge pipe, the mud from the first is usu
while that from the second, being derived mainly from
and shale, is generally clean enough to be used for firi
boilers.

When treating unclassified slack, containing all sizes u
2 inches, the washed material other than the fine surf
subjected to a final screening, giving clean coal in l
2 inches to $\frac{6}{10}$ inch; while all below the latter size i
boiler slack with about 10 per cent. of ash. The fine coa
the top of the charge at each stroke, by the last teeth in
which are deeper than the others, is received on an encl
at the back of the sieve, where the bulk of the adherent w
away, and is ultimately pushed over a shoot into a wa
to receive it.

The stroke of the piston may be varied within consider
by adjusting the eccentric so as to be available for wash
of all sizes from $\frac{4}{10}$ inch up to 2 inches in diameter. T
of strokes varies from forty-three per minute for stuff be
to fifty-five for larger sizes.

The weight of these machines is about 6 tons each.
arranged to work in pairs, each pair requiring a motive
4 to 6 HP. and one man to attend to them. The produ
12 to 18 tons per hour according to the amount of d

slack treated, or an average of 15 tons for two machines. They have been adopted, or are in course of erection, at six collieries in the north of France, and the basin of the Loire, four in Belgium, and three in Spain. In the latter country they have also been applied for alluvial gold washing in the neighbourhood of Granada.

In the introductory part of the Paper, the Author, in dealing with the theory of coal-washing, describes the method of separating coal from shale by means of a saturated solution of sulphate of zinc, in which coal floats and shale and stones sink, and its application to the assay of coal on a small scale.

H. B.

The Bessemer Process at Nischnje Saldensk.

By V. Ghrum-Ghrzhimailo.

(Gornuii Jurnal, vol. iii. 1889, p. 77; Stahl und Eisen, vol. x., 1890, p. 115.)

The Author describes a peculiar modification of the Bessemer process as practised at Nischnje Saldensk, in the Ural. The works in question have three blast-furnaces of elliptical section, which were described in February 1889,[1] and melt the magnetic ore of the neighbouring mine of Wisokaja, after a preliminary calcination. This ore, of the following composition—

	Per cent.		Per cent.		Per cent.
Silica	2·85	Manganous oxide	1·30	Copper	0·06
Ferric oxide	75·4	Magnesia	0·98	Lime	0·99
Ferrous oxide	16·71	Alumina	1·80	Phosphorus	0·03

can be reduced without the addition of any flux, and then gives only the unusually small proportion of 20 per cent. of cinder, and the metal contains only 0·2–0·3 of silicon, when smelted with cold blast; 0·6 with blast at 200° Centigrade, and barely 0·9 per cent. with the highest attainable temperature of 550° Centigrade. In order, therefore, to obtain metal suitable for the Bessemer process, an addition of silicious fluxes and manganese has been made for some years past, the average charge being—

	Per cent.
Wisokaja ore	85·6
Ball furnace cinder	6·2
Sand	4·9
Manganese ore	3·3

Each of the three furnaces working with blast heated to 540° Centigrade, and a consumption of 22 cwts. of charcoal per ton of metal, makes about 18 tons of cast iron daily, the proportion of slag, even with the addition of fluxes, being only 30 per cent. A necessary consequence of this is, the furnaces are exceedingly sensitive in work, and the silicon in the metal varies in the most

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[1] Minutes of Proceedings Inst. C.E., vol. xcvi. p. 435.

uncertain manner, from 0·8 to 2·5 per cent., so that it cannot be used in the Bessemer converter without being cast into pigs, which are then selected, mixed, remelted in a Siemens reverberatory furnace, and, when liquid, transferred as rapidly as possible to the converter, where the blowing was effected in the ordinary way. On one occasion, however, owing to an accident in the Bessemer house, the charge remained in the open-hearth furnace for an hour and a half, losing so much silicon that the fracture of the sample appeared white, and it was feared that the metal would set in the converter; but, to the astonishment of all present, the blower was very hot from the beginning, and the addition of rail crop-ends was necessary to reduce the temperature of the finished steel before casting. This unexpected result was due to the extremely high temperature of the charge before converting; it was run from the Siemens furnace at a dazzling white heat; and a repetition of the experiment showed that pig-iron containing only 0·8 per cent. of silicon could be regularly converted into steel, if introduced into the converter in a sufficiently super-heated condition.

Another development of the practice has followed the introduction of the combined open-hearth and converter system as the regular working method of the establishment. The rail-mill produces from 25 to 30 per cent. of scrap, which cannot be disposed of on the spot, but is now utilized by dissolving it in cast-iron, in order to bring the silicon in the latter to the required proportion, 0·8 per cent., for blowing. The cast-iron is brought liquid in a ladle from the blast-furnace to the open-hearth furnace, its quality being determined by the fracture of a sample ingot, and rail crop-ends are added as required, the maximum amount when dark-grey pig iron is heated being 40 per cent. In this way the consumption of fuel is reduced to that necessary for melting the scrap, the cast-iron retaining all the heat brought from the blast-furnace, while that due to the slight oxidation of silicon and manganese, which goes on in the open-hearth furnace adds to the temperature of the bath. As the proportion of carbon is diminished by dilution with finished steel, the time required for blowing in the converter is notably diminished.

The chemical changes during the progress of the operation are illustrated by a series of analyses taken during the working of two charges, approximately of 4 tons each.

Charge A.—Pig Iron, 2,560 Kilograms; Rail-Ends, 1,280 Kilograms.

Composition.	Carbon.	Silicon.	Manganese.
	Per cent.	Per cent.	Per cent.
As charged in Siemens furnace	3·06	1·31	2·37
,, Bessemer converter . . .	2·28	1·18	1·72
After blowing four minutes	1·34	0·68	1·12
,, eight minutes	0·70	0·35	0·80
,, twelve minutes	0·28	0·02	0·12

CHARGE B.—PIG IRON, 3,840 KILOGRAMS, WITHOUT SCRAP.

Composition.	Carbon.	Silicon.	Manganese.
	Per cent.	Per cent.	Per cent.
As charged in Siemens furnace	3·70	0·75	2·60
" Bessemer converter . . .	3·65	0·70	2·01
After blowing three minutes	2·50	0·56	1·31
" six minutes	1·70	0·47	1·29
" nine minutes	1·05	0·43	1·04
" twelve minutes	0·55	0·33	0·65
" fourteen minutes thirty seconds	0·28	0·03	0·31

The temperature of the metal, as charged into the converter, is believed to have been from 1,400° to 1,500° Centigrade. Both charges blew very hot, and 386 kilograms of rail-ends were added to the blown metal in A, and 112 to that in B, before casting,

The results obtained in this method are, according to the Author, in complete accordance with his researches on the German Bessemer process published twelve years since,[1] where a similar method was characterized as the Swedish Bessemer process. In the ganister lined converter two principal factors are involved, namely, the proportion of silicon in the metal, and its initial temperature. It is well established that, at the melting-point of cast-iron, 1,200° Centigrade, carbon is not affected by the blast, and that it only begins to burn at about 1,400° Centigrade, the heat required to bring the bath up to the latter point being furnished by the combustion of silicon, for which purpose 0·8 per cent. is theoretically sufficient, although practically twice as much may be required, as the energy of combustion of silicon is comparatively feeble until a considerably higher temperature than 1,200° Centigrade has been reached, and therefore a considerable quantity of the air blown in is unconsumed. When the preliminary heating-stage has been passed at 1,400° Centigrade, the boiling period begins, and a further proportion of 0·8 per cent. of silicon is sufficient to bring the bath to the temperature of molten soft iron, 1,600° Centigrade. The carbon, which burns simultaneously, contributes nothing to the heat of the bath, but only serves to determine the length of the operation. This combination of heating and boiling periods alone characterizes the English Bessemer process.

When the charge is introduced at such a temperature (1;400° Centigrade) that silicon and carbon burn simultaneously, the boiling period commences at once; and if the former much exceeds 0·8 per cent. it will, when the proper temperature for pouring has been attained, be still present in such excess as to require for its removal a supplementary period of blowing, during which the metal becomes strongly super-heated. The combination of boiling

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[1] Zeitschrift des Vereines deutscher Ingenieure, vol. xxii. p. 385.

and super-heating stages, called by the Author the German Bessemer process, depends upon the circumstance that, at very high temperatures, silicon is more slowly oxidized than carbon. Manganese has the effect of protecting silicon from oxidation, and when it is in excess of the amount required for forming a slag with the latter element, burns alone, and is removed at the expense of the converter lining, which is more rapidly corroded than is the case when the metal is poorer in manganese.

The Swedish, or ideal process of the Author, is that in which silicon does not exceed 0·8 per cent., and the blowing begins with super-heated metal, the operation being reduced to the boiling process alone. This the Author considers should be the aim of all Bessemer works to attain, the conversion being effected in the shortest time without re-carburizing. The necessary heat might be attained, where large blast-furnaces are used, by tapping at short intervals, say twenty minutes, into a collecting ladle. Four furnaces, each working 200 tons daily, would supply sufficient for three 10-ton charges every hour. This result has already been attained in America, where seven 10-ton charges are converted per hour, from metal containing, carbon 3·4, manganese 0·5, and silicon only 0·7 per cent.

Finally the Author considers that, by a very large increase of blowing power in the converter, whether by increasing the area of the twyers or the density of the blast, more complete oxidation of the carbon might possibly be obtained, with a partial formation of carbon dioxide and a corresponding increase of temperature, and, consequently, that the proportion of silicon in the metal might possibly be reduced to 0·5 per cent., and yet give perfectly good rail-steel by the Swedish method.

H. B.

Multiple Resonance of Hertz's Electrical Waves.[1]

By E. Sarasin and L. de la Rive.

(Comptes rendus de l'Académie des Sciences, vol. cx. 1890, p. 72.)

Following the procedure adopted by Hertz in his classical experiments on the determination of the position of loops and nodes in electrical waves transmitted through the ether, the Authors, by analyzing these waves by resonators of different periods of vibration, have shown that the waves emitted by the primary generator are of all lengths, and that any given resonator therefore determines the position of loops and nodes corresponding to its own special periodicity. A large number of experiments were

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[1] A somewhat fuller Abstract of this Paper has been printed in the *Electrician*, Jan. 31, 1890.

made, and under all conditions fulfilled the above-mentioned conclusions, and the term "multiple resonance" has therefore been applied to this species of phenomena. Mr. Cornu adds the remark, that these results cut away the ground from the theories based on Hertz's experiments, which consequently fail to prove the identity of light and electricity.

F. J.

The Designs of Armatures of Dynamos. By A. ISENTHAL.

(Elektrotechnische Zeitschrift, February 1890, p. 83.)

In this article the Author has attempted to establish general rules for the design of armatures when the current C, terminal pressure V, and speed in revolutions per minute n, are given. The rules are based partly on theoretical considerations, and partly on the present practice followed by leading dynamo-makers, and have been established for three distinct types of machine, viz., the disk, the cylinder, and the drum. By investigating the performance of fifteen disk machines, the Author finds that the average strength of the field is 4,500 in C.G.S. measure, and that 2·4 metres (nearly 8 feet) of armature conductor are required for every volt terminal pressure. The mean circumferential speed of armature is assumed at 4,000 feet per minute. The resistance of the armature is $0 \cdot 08 \frac{V}{C}$, and the density of current in the armature conductors is 2,500 amperes per square inch. The Author assumes that the weight of core-iron in a disk-armature is 15·7 lbs. per kilowatt output, and that the radial depth of the core is 2·5 times its thickness. From this he finds that the radial depth in inches can be given as a function of speed and output according to the expression $0 \cdot 00243 \sqrt{C\,V\,n}$.

For cylinder armatures the Author assumes a circumferential speed of 2,360 feet per minute, and a density of 2,500 amperes per square inch in the armature conductors. The strength of field in machines for moderate pressure is 2,500, and in machines for very low pressure (plating-machines) it is 1,000. One volt terminal pressure is in these two cases produced with 4·5 and 11·2 feet of armature conductor respectively. The resistance of armature in machines for moderate pressure is given as $0 \cdot 0455 \frac{V}{C}$. The weight of core-iron is assumed to amount to 22·5 lbs. per kilowatt.

Similar determinations are made for drum machines. The strength of field is given as 4,000 for moderate and 1,800 for low-pressure machines. Circumferential speed and current-density are assumed to be the same as in the cylinder machines. The length of armature conductor to produce 1 volt terminal pressure is 2·8 and 6·3 feet accordingly, as the machine is one of moderate or low-voltage, and the armature resistance is $0 \cdot 0287 \frac{V}{C}$ and $0 \cdot 0645 \frac{V}{C}$ respectively. The weight of iron in the armature-core is 27 lbs. per kilowatt. Rules are also given for the number of layers of armature-wire, depth of winding, number of coils on armature, dimensions of commutator, spindle, and pulley; and output per lb. of copper of armature-conductor.

G. K.

The 1,000-*HP. Steam Dynamos at the Berlin Central Electric-Light Station.* By F. Uppenborn.

(Elektrotechnische Zeitschrift, vol. v., 1890, p. 53.)

The first central electric-light station in Germany was erected in 1885, in the Markgrafenstrasse, Berlin, and the steam dynamos used in that case were each of 40 kilowatt output, and were then considered very large machines. It was, however, soon felt that this unit was too small, since the large number of separate machines required a proportionately large staff of attendants, and thus increased considerably the working-expenses. When it was found necessary to enlarge the station, the unit chosen for the new steam dynamos was 300 HP., and since the economic results have proved the wisdom of this step, the company known under the title Berliner Elektricitätswerke resolved to go still further in this direction, and to employ 1,000-HP. steam dynamos in their new station in the Spandauerstrasse. The vertical arrangement of the station is as follows:—Engine-room, partly underground, 54 feet by 81 feet, and 36 feet high; above it is a floor 12 feet high, in which are the horizontal flues to chimney and the offices. The top floor, which is 23 feet high and 55 feet by 83 feet in area, is occupied by the boilers. The latter are of the Steinmüller type. Five boilers are already in place, and three more will be added as required. Each boiler has 2,930 square feet of heating-surface, and is capable of evaporating 6,000 lbs. of water per hour at a pressure of 150 lbs. per square inch.

The foundation for each of the four steam dynamos is 10 feet in depth and 18 feet by 39 feet 6 inches in area. The lowest part consists of a layer of concrete 2 feet 4 inches thick, whilst the rest is brickwork. The engines are vertical compound condensing engines with cranks at 90°, and a 500-HP. dynamo at either end of the crank-shaft. The high-pressure cylinder is 29 inches in diameter, and the low-pressure 52 inches, the stroke being 57 inches. The total ratio of expansion is 1 : 14, and the valve-gear is of the Corliss type. At 75 revolutions per minute the engine indicates 1,180 HP. These engines have been built by Messrs. Van den Kerchove and Co., of Ghent, and the consumption of steam has been guaranteed not to exceed 13½ lbs. per I.HP. hour. Each dynamo is intended for an output of 2,600 amperes at 140 volts terminal pressure when the speed is 80 revolutions per minute. It has, however, been found that this output can already be obtained at from 60 to 64 revolutions per minute. The exciting energy required is 2 per cent. of the output, and the loss of pressure due to armature resistance is 2½ per cent. Each dynamo weighs about 26 tons. These machines have been built by Messrs. Siemens and Halske, of Berlin, and have internal field-magnets. The armature has Gramme winding, and surrounds the star-shaped field, which consists of eight magnets of rectangular section placed radially over a circular yoke-ring, which is attached to a U-shaped casting placed outside the fly-wheel. This casting is stayed to the engine frame. The spindle passes through the yoke-ring, and carries a star-shaped wheel, to which the armature-core is fastened by insulated bolts. The armature-core consists of sheet-iron disks insulated from each other in the usual way, and the winding consists of straight bars on the outside and U-shaped bars on the inside. The outside bars serve not only as winding, but form at the same time the commutator, for which purpose the armature is turned up on the outside after winding. The current is collected by ten sets of brushes all separately and simultaneously adjustable. The external diameter of the armature is 10 feet. The Author does not give any data as to the winding and dimensions of the various parts, but the latter can be gathered from the drawings illustrating the article.

G. K.

Mains for High-Pressure Alternating Currents.

By C. Jacquin.

(La Lumière Électrique, vol. xxxv., 1890, p. 354.)

The Author treats this subject from two points of view; first as regards loss of current by leakage, and secondly as regards loss of energy by induction. It has been shown by Foederreuther that the insulation resistance of a cable diminishes by 10 per cent. if the pressure be increased from 1 to 100 volts, and assuming this ratio to hold good for higher pressures, the Author finds that the insulation resistance of a 2,000-volt cable must be twenty times that of a 100-volt cable. The specification for the cables to be used in connection with the 2,400-volt alternating currents supplied from the Municipal Station at the "Halles," Paris, stated that the insulation shall be 1,000 megohms per kilometer, or about 624 megohms per mile. The equivalent insulation of a 100-volt cable would at this rate only be 26 megohms per mile, by no means an excessively high figure. Moreover, the insulation of the cable is further reduced by joints, and it was, in the case of the "Halles" installation, specified that the insulation of the cable after laying should not be reduced by more than 10 per cent. The insulation employed by some German and Austrian cable-works is jute impregnated with some resinous compound, and the insulation resistance immediately after manufacture is given as from 310 to 375 megohms per mile. These standards the Author thinks cannot be maintained, since all fibrous substances are hygroscopic, and with the admission of moisture the insulation must be lowered. As a matter of fact, such cables after laying have never reached even 62 megohms per mile. The Author gives the following formula for the insulation resistance of high-pressure cables—

$$M = \rho \frac{l}{E},$$

in which ρ is the total insulation resistance, l the total length in kilometers, and E the pressure in volts. The coefficient M is 400,000 ohms per volt per kilometer of the cables used at the "Halles" installation, and the Author considers a cable to have become unsafe if M has decreased to 10,000 ohms per volt per kilometer.

The Author next investigates the induction-effect of alternating-currents in cables. He shows that two simple unarmoured cables, laid side by side, are likely to disturb neighbouring telephone lines, which disturbance can be avoided by the employment of concentric cables. If single cables are individually provided with iron armour, or if two single cables are placed within the same iron tube, exterior disturbance is also avoided, but a certain loss of energy is incurred, consequent on the magnetisation of the iron. The magnetic circuit, in the case of single armoured cables, is completely closed, but in the case of two cables within the same iron pipe the lines of force flow partly through air and partly through iron, and the waste of energy is less. The Author has made experiments to determine this waste of energy in a cable of 220 yards length, laid in the works of Mr. H. Ménier, at Grenoble. The cable was looped to bring its two ends close together, and these could be joined, by means of a special switch, with the terminals of a dynamo and those of an alternator. There were in circuit a rheostat, a wattmeter, and a dynamometer The experiments were made in the following manner: The switch was placed to the alternator, and the readings of the dynamometer and wattmeter were noted. The switch was next placed to the dynamo, and the rheostat adjusted, until the dynamometer indicated the same current as before. The wattmeter indicated now simply the loss by ohmic resistance, and this reading deducted from the previous reading, gave the loss due to hysteresis and eddy-currents in the previous experiment. Three cables were thus tested; the first having no metallic covering, the second having a lead sheath, and the third being covered by lead and armoured with iron wires. The copper conductor of all the cables had a sectional area of 0·0465 square inch, insulated by pure rubber. The frequency of the alternating-current was 50 cycles per second. The current was 18 amperes. In the first cable no energy was lost beyond that due to ohmic resistance. With the lead cable two experiments were made. In the first the cable rested on the ground, and the two ends of the lead tube were not otherwise connected; whilst in the second they were short-circuited by a copper wire. The losses were respectively 1 and 2 per cent. of the loss due to ohmic resistance. With the armoured cable three experiments were made, namely, (*a*), the ends of lead and iron covering insulated; (*b*), lead covering insulated, and iron covering connected; and, (*c*), lead and iron covering connected. The losses in these cases were respectively 18, 27·4, and 34·5 per cent. of the loss due to ohmic resistance. With a frequency of 25, all the losses were about 60 per cent. of their former value. The experiments were not repeated with a higher frequency than 50, but the Author estimates that, with a frequency of 100, the loss in the most unfavourable case, (*c*), would not exceed 50 per cent. of that due to ohmic resistance, or, say, 2·5 per cent. of the total energy flowing through the cable.

The Author next discusses the relative merits of concentric and twin cables, and comes to the conclusion that the latter are preferable, not only on account of their greater insulation resistance, and consequently greater safety, but also because they are cheaper, the ratio being in one special case cited as 2 to 1.

G. K.

The Spiral-Coil Voltameter. By HARRIS J. RYAN.

(Electrical Engineer, New York, 1889, p. 522, 3 Figs.)

The copper voltameter has been extensively used at Cornell University for calibrating Thomson graded galvanometers, tangent galvanometers, and other measuring instruments. The plate form of copper voltameter has been thoroughly investigated by Mr. Thomas Gray of Glasgow; but it has been found very difficult for students to obtain accordant results with his methods. A new form has therefore been devised with the object of obtaining a wide range of current density through which deposits would be as firm and adherent as possible. Wire coils in place of plates seemed to possess many advantages. The coils are hung vertical, the kathode being of smaller diameter and arranged inside and concentric with the anode, the diameter of the latter being about 1¼ to 1½ inch larger than the former; wires of suitable size can be cleaned and coiled without being handled. The loss-coil, thus prepared, is ready for use. The surface of the gain-coil must not be touched by the hand; after polishing it is washed by being plunged into a jar of water containing a little H_2SO_4, it is then rolled on filter- or blotting-paper to remove all but a mere film of the water. The coil is then dipped in 95 per cent. of alcohol, removed, and the excess of alcohol allowed to drip into the jar of the same. By rolling the coil on clean filter- or blotting-paper again nothing, but a mere film of alcohol remains, and that is thoroughly evaporated in a few moments, leaving the coil entirely dry. A coil 2½ metres long, of No. 16 wire, is used, having a surface area of 100 centimetres. For great strengths of current a number of these are arranged in parallels. For every four amperes one wire is necessary. At the end of the deposit the gain-coils are immediately removed and plunged first into clean water, and then into the acidulated, from which they are dried by means of alcohol in the manner above described. When dried they are at once ready to weigh. The copper sulphate, water, and acid need not necessarily be chemically pure. The density of the voltameter solution should be not less than 1·10 and not more than 1·18. When copper is immersed in a saturated solution it passes slowly into solution in an irregular way, and this is assisted by the current; from the extensive experiments at Glasgow it is now possible to make determinations with absolute accuracy to within $\frac{1}{10}$ or even $\frac{1}{20}$ of 1 per cent. The Author contends that with the spiral-coil form, which presents a regularly curved surface the copper from the kathode goes into solution in a more regular way than with the plate form; also the fact that the plane of each turn of wire is disposed horizontally is a great advantage, for in this way the solution is not allowed to become weak near the kathode nor dense near the anode. He then alludes to Mr. Shaw's experiments at Emmanuel College, Cambridge, and shows a series of curves plotted from the results obtained, and states that, with a current density of one ampere for every 50 square centimetres exposed, the amount of copper deposited will be 0·0003287 gram per coulomb, the ratio of silver to copper deposited being 3·401.

The Author believed that less copper should be dissolved from kathodes of the spiral coil form than from those of the plate form. For proof of this four cells were made, two in plate form and two in coil form. One of each pair had an area of 10 centimetres and the other of 100 centimetres, and a current of half an ampere was passed through; a table of results is given from which it appears that about 1·8 gram of copper was deposited per ampere per hour with the larger coils. In the discussion which followed the reading of the Paper all agreed as to the great difficulty in obtaining accurate results with the plate form; and Professor Nichols stated that, whereas formerly errors of 1, 2, 3, or 4 per cent., according to the ability of the student, were expected, now errors of $\frac{1}{10}$, $\frac{2}{10}$, or $\frac{3}{10}$ per cent. only were obtained, and if the error reached $\frac{3}{10}$ the student was told something was wrong.

E. R. D.

Self-Regulating Brake. By Professor A. FLIEGNER.

(Schweizerische Bauzeitung, December 7, 1889, p. 138.)

The Author describes an improved form of the differential brake first brought out by Mr. Marcel Deprez, which has been introduced in the mechanical laboratory of the Polytechnik School in Zürich. In the new brake the jaws and blocks employed by Mr. Marcel Deprez are replaced by a continuous brake-strap and the differential lever is weighted at its inner end exactly in line with the axis of rotation; an arrangement which presents no difficulty when the brake-pulley is overhanging. If the shaft passes through the brake-pulley the inner end of the differential lever is curved to a circle large enough to clear the shaft, and the weight is applied by means of a small roller. In consequence of this arrangement the weight does not directly produce any torsional moment, but simply serves to keep the brake-strap more or less tight according to the angular position of the differential lever. The measuring-weight is applied directly to the strap in the usual way.

G. K.

An Improved Prony Brake. By — HILLAINT.

(Comptes rendus de l'Académie des Sciences, Paris, vol. cix., 1889, p. 798.)

In the ordinary Prony brake the weight applied produces a certain friction in the journals of the brake-wheel, the corresponding energy of which is not registered. To obviate this source of error the Author employs a system of levers by which power is applied to the brake-strap in two diametrically opposite points, thus relieving the journals of all additional pressure. The force is registered on a spring-balance. One of these brakes was employed to ascertain the efficiency of an electric transmission plant furnishing power to the Chevrant Paper Mills at Domène (Isère). The distance of transmission is 3 miles, the electromotive force is 2,850 volts and the current 70 amperes. The resistances are as follows: generator 1·934 ohm, line 3·474 ohms, motor 1·421 ohm; total, 6·829 ohms. The electrical efficiency at full load is 83 per cent., and the commercial efficiency ascertained by brake-trials varied between 63 and 68 per cent. It was found that with a brake-wheel 39½ inches diameter and 16 inches width, revolving at 240 revolutions per minute, 300 HP. could be conveniently absorbed.

G. K.

The Municipal Electric-Light Installation in the Paris Markets.

By R. Audra.

(Le Génie Civil, vol. xvi., 1889, p. 113. 19 Figs.)

Many electric-light companies have been started in Paris, and the Town Council resolved to make an installation in the basement of the markets and supply the neighbourhood with electric light both for street lighting and for use in private houses, clubs, shops, &c. The Author proceeds to give an historical sketch of the progress of electric lighting in Paris up till the present date, and then to describe the scheme above mentioned. A preliminary scheme was laid before the Council on the 4th of November, 1887, and was calculated to light up all the markets and the basement as well as the surrounding streets; the first cost was put down at £34,000, and the cost of maintenance at £7,440 per annum. It was intended by the promoters to act as a model installation, and would, it was thought, enable the Town Council to force improvements upon the private companies, and also enable them to regulate the tariffs to be charged by practical experience. The Council was not inclined to proceed on these lines, intending to work commercially and not have merely a laboratory for experiments. On the 30th of December, 1887, a vote of £40,000 was granted for the purpose of creating a municipal installation to supply electric light to private consumers. It was thought impracticable to buy out all the electric-light companies in existence in order to supply the whole by the Municipality, as it would have entailed an outlay of £20,000,000. After long discussion the Council issued a notice for the Administration to draw up in July 1888 a new scheme to obtain tenders for the material, the cables were to be allowed to be placed in the sewers; the price to be charged for town lighting was 10*d.* per Board of Trade unit and that to private consumers 1*s.* 3*d.* per Board of Trade unit. The space occupied is at the corner of the Rue Rambuteau and the Rue Vauvilliers in the basement of the markets. The power employed is about 840 HP. There are three separate circuits for supplying the current, of which two supply a circle of about 650 yards radius and are worked at low tension; the third is worked at high tension. The installation is divided into six groups of about 140 HP. each a third of the power being held in reserve in case of breakdown, as is required by the statutes referring to the supply of electric light to the public. Each group consists of an engine and dynamo, and is independent of the others. The boilers are six in number, and supply steam to a common receiver; the condition imposed upon the makers was to supply boiler-power sufficient to evaporate 2,240 gallons of water per hour into dry steam. A Commission, consisting of experienced engineers, was named to select from the tenders the most suitable plant, with the result that on Dec. 29, 1888, the following were accepted:—Messrs. Belleville & Co. to supply the six boilers at a cost of £2,980; Messrs. Weyher to supply three triple-expansion engines of 140 HP. each for £3,840, and a pump for £160; Messrs. Lecouteux & Garnier to supply three single-cylinder engines of 170 HP. each for £3,060, and a pump for £108; the Edison Continental Co. to supply six direct-current dynamos and fittings for £1,746; Mr. Patin, on behalf of Messrs. Ferranti & Co., three alternate-current dynamos of 113,000 watts each for £3,842.

Boilers.—These are of the most recent type made by the firm, and similar ones were exhibited at the recent exhibition in Paris. The grate-surface is 30·55 square feet, and the heating-surface 784·4 square feet; there are two donkey-pumps, each capable of delivering 2,200 gallons per hour, and two superheaters. The space reserved for the dynamos and engines is 31 yards by 59 yards, divided by columns into squares of 6½ yards by 6½ yards, and there is room enough to double the power at present in use.

The inside masonry work, chimney, foundations of the engines, &c., was contracted for at £2,670.

Steam Engines.—The three engines by Messrs. Lecouteux & Garnier are of the Corliss type, but with modifications by which steam can be admitted up to $\frac{8}{10}$ of the stroke; they work at 180 revolutions and drive the Ferranti dynamos direct by cotton ropes at 500 revolutions. Those by Messrs. Weyher & Richemond are of the vertical marine type, triple expansion and condensing, and the steam is expanded to twelve times its original volume.

There is a fly-wheel at each end of the shaft used as a pulley, for driving the dynamo by a strap, and in one of the wheels is placed the governor. The engines work at 160 revolutions, and drive the Edison dynamos direct at 600 revolutions per minute.

Dynamos.—The Edison machines are worked on the three-wire system, and the arrangement of the switch board is of a special type by the Edison Continental Co., and cost £1,760 including the necessary measuring instruments. The Ferranti machines have an E.M.F. of 2,400 volts. There is no iron in the revolving armature, and the two halves of the frame carrying the field-magnets can be separated by unbolting, and then can be moved laterally along the bed to allow of thorough examination of the machine. The armature is 3 feet 7 inches in diameter and $\frac{9}{16}$ inch thick, and the distance between the poles $\frac{3}{4}$ inch; the exciter is carried upon a bracket and its armature is upon the main armature shaft. There is no need of a rheostat for regulation, for by reason of the absence of iron in the armature, and its slight resistance, differences in the load affect the potential but slightly, and it is sufficient to keep the speed constant and notice occasionally the reading of the voltmeter. There are, as before stated, three wires from the dynamo, the glow lamps being placed in parallel between the central wire and one of the others, the arc lamps being run four in series between the two outside wires. The lamps also are arranged on two independent circuits so that part may be extinguished if need be. For the external lighting, provision is made for two thousand lamps of 60 watts each, of which fifteen hundred can be lighted at the same time. Although the Administration had full powers to place all the cables in the sewers, they did not do so because of the great number of cables already placed there, the moisture always existing which renders necessary an expensive type of insulation, the danger of injuring the telephone circuits in such close quarters, and the risk of injury by the numerous persons employed in the sewers. A special type of channel has therefore been made of cement in form of a box with lid. At certain distances inside are small wooden supports carrying iron hooks which hold up the cables; these channels are placed just under the side-walk, but where they cross the road they are placed 1 yard below the surface as the soil is much moister. The cable of the double circuit was divided into two lots, one for the markets, and the other for the external circuit. The former was given out to the India-rubber Company at Persan-Beaumont at a price of £880, the latter to Messrs. Menier & Co. at £2,480. The Author then gives details of the manufacture of these cables. In one part of the streets the side-walk is too narrow to allow of the cement channels. So here recourse has been had to the sewers, and a cable containing positive and negative leads, arranged concentrically, has been used, and as no branches are taken off in this part for private consumers no difficulty has been experienced. The high tension leads consist of about 981 yards of cable containing the two leads and 6,320 yards of single cable. The cost of both together was £2,960 and, as before stated, the high tension is worked at 2,400 volts, the low at 100 volts. Transformers of the Ferranti type are used to work with the machines which make 9,500 alternations per minute. The price charged was £4 for 736 watts, or 15*s.* 10*d.* for 100 watts, so that the first cost was £1,228 for the 226,000 watts. The arc lamps are by various makers and cost £2,600.

Details are then given as to prices charged to the consumer, use of meters, mode of wiring, &c.

E. R. D.

The Electric Lighting of Frankfort-on-Main.

(Elektrotechnische Zeitschrift, vol. v., 1890, pp. 109 *et seq.*)

This is a joint report addressed by Professor Galileo Ferraris, Dr. Kittler, Mr. W. H. Lindley, Mr. F. Uppenborn and Dr. H. F. Weber, to the Mayor of Frankfort, on the various proposals for a central electric lighting station for that town. This Commission of experts was instructed to report upon (1) the comparative merits of direct- and alternate-current supply; (2) the question of safety, general applicability of supply and cost of working; (3) the best system to be adopted. The various points on which the Commission was asked to pronounce an opinion were stated in the form of questions, and those questions coming under the headings (1) and (2), were as far as possible experimentally investigated, and the answers given unanimously. As regards heading (3), the commission did not give a joint opinion, but the members reserved to themselves the right to give their individual opinions if the town authorities should desire this. The joint opinions are grouped as follows:—

Danger.—With the apparatus properly installed and carefully handled there is no danger to members of the staff. With careless handling the danger is the same, whether the current be 2000 volts alternating or 2000 volts direct. The transformers are to be placed in sub-stations, and only the 100 volt currents taken into the houses of subscribers. There is thus absolutely no danger for subscribers. By proper safety-devices it is also possible to avoid all danger with the Siemens 5-wire system, which requires 500 volts direct currents.

Alternate-Current Motors.—A 25-HP. and a 5-HP. Ganz motor were tested. The efficiency of the larger machine varied between 82 and 83 per cent., the power varying between 15 and 35 HP. The smaller machine gave 78 per cent. when loaded to 5 HP., and when the load varied between 3 and 8 HP. the efficiency varied between 60 and 80 per cent. There is thus only a very small difference in the efficiency between the alternate and direct current motor, and in this respect both may be considered equally applicable. The alternate-current motors must be started by hand and without load, the time occupied until they work normally ranging from thirty to forty-five seconds. They cannot be so safely overloaded as direct-current motors. The large motor showed during starting considerable development of sparks at the commutator, the length of sparks reaching 2 inches, whilst at each start about 17 milligrams of copper were wasted from brushes and commutators. This waste is not considered to be serious, neither is the fire risk consequent upon sparking of importance. The large motor worked somewhat noisily, but the smaller motors worked sufficiently quiet for domestic use. The large motor could be gradually overloaded to 40 HP., or by 60 per cent. of its normal power without losing its synchronism; with a load of more than 40 HP., even if gradually applied, the motor pulled up. Loads up to 26 HP. could be suddenly applied and removed without loss of speed, but a load of over 26 HP., suddenly applied, caused the motor to stop. In view of this behaviour, the Commission recommends that the nominal power of the motors chosen should exceed the normal power required in each case.

Alternate-Current Transformers.—The efficiency of medium-size transformers was found to be from 95 to 96 per cent. at full load; 93 to 94 per cent. at half load; 90 per cent. at quarter load, and from 80 to 82 per cent. at one-eighth load. Full load has been taken as that load at which no part of the apparatus reaches a temperature higher than 80° Centigrade above that of the room. To increase the average efficiency of the whole system, the Commission recommends the employment of transformer sub-stations provided with automatic apparatus for varying the number of transformers at work in each group. Such an apparatus, costing about £7, has been submitted by Messrs. Ganz & Co., and found to work safely and without sparking. The firm offers to maintain the transformers in consideration of an annual payment of 6 per cent. of their cost price.

Arc Lamps.—Alternate- and direct-current arc lamps were compared, and it was found that with equal energies (including the loss in resistances required for parallel working of direct current lamps) the illumination was as 4 to 5, showing a gain of 20 per cent. in favour of the direct-current lamp. Three alternate-current lamps could be run in series from a 105-volt circuit. The consumption of carbon in an alternate-current lamp exceeds that in a direct-current lamp requiring the same energy by about 20 per cent.

Direct-Current Transformers.—The commission is not aware that such machines have yet been practically used. The proposal to wind the primary and secondary circuits upon the same armature core must be rejected as unsafe, but there is no reason to doubt that transformers with two distinct armatures will work satisfactorily and safely. The efficiency of 82 per cent. estimated by Messrs. Schuckert & Co., in their project is attainable at or near full load.

Storage Batteries.—On this subject the Commission could not agree, and the members therefore gave their opinions individually. Ferraris pronounces against them. Weber, whilst dissatisfied with their efficiency, thinks their life satisfactory, and leans to their adoption in Frankfort under the maker's guarantee. Upperborn is in favour of storage batteries, as is also Kittler, who has especially a good opinion of the "Tudor" accumulator.

Five-Wire System.—The Commission rejected the five-wire project previously offered by Messrs. Siemens and Halske, but thinks the new project a considerable improvement. It has, however, not yet been practically used. Regulation and balance between the wires is obtained by small dynamos erected in nine sub-stations throughout the town. The Commission objects to the complicated nature of the project which requires the laying of five wires on each side of the streets.

G. K.

The Electric Lighting of Hanover. By Prof. Dr. W. Kohlrausch.

(Elektrotechnische Zeitschrift, vol. v., 1890, p. 69.)

This is a report on various schemes for the establishment of a central electric-lighting station at Hanover which were submitted to the municipality of that town by different firms. The tendering firms were: The Deutsche Elektricitätswerke, Aachen;

the Helios Company, Cologne; Messrs. Siemens and Halske, Berlin (two schemes); and Messrs. Schuckert & Co., Nürnberg (two schemes). In all cases, condensing engines are proposed and direct-driven dynamos. All the schemes, with the exception of that proposed by Helios, comprise low-tension continuous-current distribution from a common net-work; The Helios Company proposes high-tension distribution by means of transformers placed in the houses of subscribers. The total capacity of the station is assumed at 700 kilowatts, or about 1,000 E. HP. at the points of consumption, and the following Table gives the voltage and maximum percentage loss of pressure proposed by the different competitors:—

Scheme.	Voltage.	Loss of Pressure.
		Per cent.
Aachen	100 to 135	35
Schuckert (I) . . .	217 „ 235	10
Siemens (I and II) . .	220 „ 253	16
Schuckert (II) . . .	2,000	5
Helios	2,000	3·6

The Aachen, Siemens, and Schuckert schemes, comprise the employment of storage batteries, the efficiency of which is estimated at 75 per cent., whilst the contractors offer to keep the batteries in good order during a period of ten years for a yearly payment of from 4 to 5 per cent. of their cost price, and to hand them over in perfect working order at the end of that time.

The Aachen scheme is for seven boilers and seven steam-dynamos, the latter running at one hundred and eighty revolutions per minute. Battery-power for four thousand lamps burning 3·3 hours is provided, but it is intended to give the greater part of the supply direct from the omnibus bars in the station by means of ten feeders, each feeder having inserted a Lahmeyer motor-generator by which the pressure can be raised as required in order to make up for voltage loss by ohmic resistance. The power of these motor-generators varies between 10 and 30 E.HP. The Helios Company proposes nine boilers and six steam-alternators, the latter running at eighty-five revolutions per minute, and producing primary currents of 2,000 volts, which are transformed into 33, 66 or 100 volt-currents at the points of consumption.

Siemens (Scheme I) proposes four boilers and three steam-dynamos running at one hundred and fifty revolutions per minute; also battery-power for four thousand lamps burning 3·3 hours. Schuckert (Scheme I) proposes five boilers and three steam-dynamos running at one hundred and thirty revolutions per minute, and battery-power for six thousand four hundred lamps burning 3·3 hours. In both cases the dynamos and batteries are arranged in parallel, and the distribution is on the three-wire system, with regulating cells in the feeders to compensate for their ohmic resistance. In the second scheme submitted by Siemens there is provided very much more battery-power, entailing a considerably greater capital outlay and also greater working-expenses, for which reasons the Author prefers the first scheme. For Schuckert's second scheme the central station is placed 1½ mile outside the town, and is used for the production of 2,000 volt continuous currents, which are led to a sub-station within the town where they are converted by motor-dynamos into low-pressure currents. The Author objects to this scheme on account of its greater complications, and prefers the first Schuckert scheme. The working expenses in all cases have been calculated on the basis of annual lamp-hours, but the Author assumes that the number of hours during which each lamp will be used will vary with the total number fixed. For the completed station, feeding twelve thousand lamps, he estimates a lighting time of five hundred and fifty hours for each lamp per annum; for six thousand lamps, six hundred hours, and for three thousand lamps, seven hundred hours.

The Table gives total cost and cost per lamp of each scheme when fully carried out, so that twelve thousand lamps may be simultaneously alight out of fifteen thousand lamps fixed.

——	Aachen.	Helios.	Siemens (I).	Schuckert (I
	Marks.	Marks.	Marks.	Marks.
Total cost	1,077,000	1,587,000	1,148,000	1,163,000
Cost per lamp fixed . .	72	106	77	78

G. K.

Renard's Portable Electric Lamp.

(L'Industrie Moderne, 1890, p. 6, 1 Fig.)

Many attempts have been made to obtain a primary battery which could be used to supply current to an electric lamp, but there are many objections to most of the forms. The necessity for constant attention to the liquid used; the feeble electromotive force produced by a single cell; the want of constancy in the power developed, and the objectionable nature of the gases given off, are in most cases great disadvantages. The Author states that the Renard battery overcomes these difficulties; that the electromotive force produced is very high, and there are no acid vapours produced, as with the two-fluid Bunsen cell, which prohibits the use of the latter in the house. It possesses all the advantages of the bichromate cell, with the difference that it is perfectly regular in action, developes five times the power, and that, with a given weight, the liquid employed gives off 50 per cent. more energy than that used in the bichromate cell. There is no deposit of crystals, so that it is easily cleaned even after long disuse. The electric lamp is arranged upon a vase-shaped stand, which contains the cells; all the connections are made permanently upon an ebonite plate, the surface of which does not require cleaning. The glass cells are sealed by means of sockets into a copper plate, which forms the cover of the vessel containing the cells. There is a hole in this cover by which the liquid is introduced, and when at its normal height it does not reach the zincs, which thus do not waste away. When the battery is to be used, the hole in the cover is stopped up, and air is blown into the vessel by an india-rubber ball. The liquid then rises in all the cells at the same time, and it is only necessary to close the circuit in order to obtain a current; the current can be regulated by allowing air to escape, or forcing more into the vessel, and by allowing all the air to escape the current is stopped. When the liquid is used up, it is drawn from the vessel by a syringe. The whole is as simple as an ordinary domestic lamp, and, if the containing vessel be occasionally washed with clean water, it will remain in good order. Those which are now made are provided with seven cells and a glow-lamp, supported on a stalk rising from the vessel.

The main particulars are:—

Total weight, including liquid	35·2 lbs.
Height of battery without lamp	15 inches.
„ „ with „	33 „
Diameter of vessel	11¾ „
Electromotive force of battery	10 to 11 volts.
Strength of current	4 amperes.
Watts produced	40 to 45
Candle-power of lamp	25[1]
Duration of light normal	5 hours.
„ „ maximum	8 „
Price of materials for one charge	2*s*. 1*d*.
„ light per candle-power per hour	0·2*d*.

E. R. D.

Electrical Chain-Haulage in the "Consol. Paulus und Hohenzollern" Coal-Mine, near Beuthen, Silesia. By — BRAETSCH.

(Zeitschrift für das Berg- Hütten- und Salinen-Wesen, 1889, p. 379.)

The gallery in which chain-haulage is employed is about 500 yards long, having a double line of rails, of 25-inches gauge; the number of wagons dealt with per shift of ten hours being eight hundred, weighing 440 tons. The Author gives a detailed description of the chain arrangement, of which the following is a

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[1] *Sic*, probably about 12 candle-power.

short account:—In a continuation of the gallery is situated the driving-drum, 6·55 feet in diameter, mounted on a vertical axis, around which the chain is wound one and a half times. The chain having been conducted over a system of tightening-pulleys, it is guided into the centre of each line of rails, one for the full and one for the empty wagons. At the opposite end of the gallery it passes around a vertical pulley 4·8 feet in diameter, equal to the distance from centre to centre of the rails. The bearings of this pulley rest in a channel-iron so as to admit of tightening. The links of the chain are 0·80 inch in diameter, and it weighs 15 lbs. to the yard. It rests on the top of the wagons, and is kept in that position by two vertical projecting pieces. The wagons are placed at intervals of 20 yards on the chain.

The current is supplied from the surface by a flat-ring dynamo (Schuckert's system), driven by a 60-HP. twin-engine. Running at 680 revolutions per minute, this machine gives a current of 26,433 watts, equal to 35·9 HP. (1 HP. = 736 watts). The current is conducted down the shaft to the motor by a copper cable 320 yards in length, consisting of nineteen strands of wire each 0·064 inch in diameter, giving a total metallic section of 0·059 square inch. The cable is insulated with gutta-percha and enclosed in a lead pipe. The motor in the mine is also a flat-ring machine, developing a maximum HP. of 28·8 when running at 700 revolutions per minute. Between the motor and the chain-drum intervenes a system of geared wheels, which reduces the speed down to 10·5 revolutions per minute, giving the chain a velocity of 3·5 feet per second. The dynamo and the motor are both provided with ampere-meters having a range of 80 amperes and resistance coils, by means of which starting is effected gradually, and the current afterwards maintained at from 38 to 42 amperes, the working rate. The power required was calculated according to Braun's formula as follows:—

$$P = n\,(W + 2w + 2c)\,f = 1{,}694 \text{ lbs.}$$

Where P = tension in the chain, W = weight of contents of wagon = 1,210 lbs., w = weight of empty wagon = 884 lbs., c = weight of chain between wagons = 352 lbs., n = number of wagons on chain = 46, f = coefficient of friction = 0·01.

The actual work done by the drum was calculated from the following formula:—

$$A = \frac{M \cdot v}{550} = 8 \cdot 9 \text{ HP.}$$

where M = 1·05, P = 1,778, v = velocity of chain in feet per second = 2·69.

The following Table gives the results of experiments with a brake dynamometer, the speed of the dynamo being 680 revolutions per minute:—

No.	Amperes.	Volts.	Ohms.	Watts.	Dynamo HP.	Motor HP.	Per cent.
1.	66	400·5	6·008	26,433	35·9	28·72	79·9
2.	60	402	6·700	24,120	32·7	26·16	80·0
3.	57	405	7·105	23,085	31·3	24·04	76·8
4.	53	403·5	7·613	21,385	29·0	23·24	80·0
5.	48	402	8·375	19,296	26·2	20·97	80·0
6.	42	396	9·429	16,632	22·6	17·08	75·5
7.	37	388·5	10·500	14,374	19·5	15·63	79·9
8.	32	375	11·719	12,000	16·3	13·04	80·0
9.	26	348	13·385	9,040	12·3	9·84	80·4
10.	19	300	15·789	5,700	7·7	6·16	80·0
11.	12	235·5	19·629	2,826	3·8	3·04	80·0
12.	4·5	116	28·000	522	0·7	0·56	80·0

Experiment No. 6 represents the usual working conditions. Of the original horse-power of the engine, which was 25, only 8·9 was realized at the chain-drum. Between the engine and the dynamo 2·4 HP. or 9·6 per cent. were lost, the motor 7·92 HP., or 32 per cent., to the chain-drum 16·1 HP., or 64 per cent., *i.e.*, the efficiency was 36 per cent. of the engine-power and 39·3 per cent. of the dynamo-power. This is 7·3 per cent. lower than Siemens' electric locomotive.

The total cost of the installation was £2,277, of which the principal items were, the chain, £310; dynamo, £165; motor, £135; steam-engine and foundations, £685. Comparing this with the cost of direct hauling with engine under ground, it is £450 more expensive.

The working expenses for the year 1888 of three hundred and two and a half working shifts, were £214, giving 14*s.* 2*d.* per shift. The average amount hauled was 302 tons for a distance of 1,187 yards per shift, equal to 0·944*d.* per ton-mile, and including amortisation of capital at 10 per cent., 1·19*d.* per ton-mile. In another part of the same mine, where electric locomotive haulage is employed with 375 ton-miles per shift, the cost is 1·44*d.*

The Author remarks that the system is capable of dealing with much larger quantities; when fully working, the cost will be reduced to 0·60*d.* per ton-mile.

Compared with the old system of horse-hauling, a saving of £278 per annum is effected, which will return the capital in eight years.

H. L. C.

Application of Electricity to Street Railways. By F. J. SPRAGUE.

(Electrical World, New York, vol. xv. 1880, p. 147.)

The Author in this Paper, read before the Electric Light Convention at Kansas City, reminds his audience that six years ago there were scarcely a hundred electric motors in use in the United States for any purpose, and that now there are not less than fifteen thousand in use, applied to two hundred different industries. After sketching the origin of electric railways, and referring to the earlier examples, the Author divides the subject into three heads: (1) the system of independent units operated by storage-batteries; (2) the direct system of supply by an underground conductor; (3) direct supply by an overhead conductor. Although the storage-battery has been greatly improved, yet it is still necessary to have a weight of about 3,500 lbs. to propel an ordinary street-car, and it is simply impossible to work upon grades which are at all severe, owing to the low discharge rate. The Author believes that, with care, it is possible to operate a storage-battery on grades not exceeding 1 in 25, and with limited speed and daily mileage, at an expense about equal, or a little less than that of horses, but still at about double the expense necessary upon a suitably-erected and properly-operated overhead system.

Nowhere in the United States is serious storage-battery work being done. On the overhead service many cars make 150 to 160 miles per day, and even up to 180 or 190. At Denver, Cleveland, Allegheny City and Boston, the conduit system was tried, but is everywhere now abandoned except on the short section at Allegheny City.

Good sewerage is absolutely necessary, as the conduit must be perfectly well drained. The most marked advance is the single-trolley overhead system, introduced by the Sprague Company two and a half years ago, the first practical line being that of the Union Passenger Railway Company at St. Joseph, with a small 7½-HP. motor, single-geared; it was a road about 12 miles in length, with thirty curves, some of very short radius, with grades as steep as 1 in 10. The machines worked on a 400-volt grounded circuit. There are now a hundred and thirty towns or cities in the United States with one or more electric railways in operation, in construction, or under contract; these roads comprise about 1,500 miles of track, equipped with one thousand seven hundred motor cars and three thousand motors, of an aggregate capacity of 4,500 HP., and steam and electrical generators of 25,000 HP.; the roads in operation are making 100,000 miles per day, and in three months the mileage will be doubled. The objection raised by the municipal authorities in some instances, on the ground of danger to life from the current, may be met by the assertion that, although eighty lines are now in operation, and numerous shocks have been received by the employees, no serious injury has ever ensued; so that it may be safely asserted that a continuous current, having an electromotive force of 500 volts, is not dangerous to life. Grades of 12½ per cent. to 14 per cent. have been ascended by a motor car pulling a tow-car; in crowded cities the speed has increased 50 per cent., and in the suburbs speeds of 20 miles an hour are made. Not only has the possibility of running faster down grade been attained, but it is attended with a higher degree of safety; for in the event of an accident to the brakes, the car can be brought to a standstill by reversing the current in the motor.

Distances up to 6 miles have been operated from one station. In a Paper read in August 1888, before the American Institute of Electrical Engineers, the Author made an estimate of the expense of operating a thirty-car road, and divided the operating expenses under the heads: (1) those belonging to the central station; (2) the road operating expenses; and gave for the two combined, excluding salaries, taxes, &c., for the motive-power alone, the sum of 2·15*d.* per car-mile, and stated that this was 40 per cent. of the cost of operating by horses. This estimate has been fully borne out by experience. Although ground returns have been given up in incandescent lighting, from the danger of fire in buildings, and in arc-lighting circuits from the danger to life, yet there is no objection in the case of street railways to the use of the rails as a return-circuit, as there is no risk of fire, and the wires are quite out of reach. There has been considerable difficulty with the telephone companies, who complain of interruption owing to induction from the railway companies' wires, but this has been quite obviated by using a metallic return for the telephones; and customers who have once used a telephone upon an exchange which uses a metallic return, will never afterwards be satisfied with a ground return.

In street-car practice, progress has been made from one-car units, to trains of two, three, and even four cars in the street, and forty cars have been operated from a single station. Considering, then, the question of applying a similar electrical system of traction to existing railways worked by locomotives, the Author takes the case of the railway from Jersey City to Philadelphia, 90 miles in length, and says that, with his system of the overhead wire, slight grades make but little difference in the general result, especially if the grade percentage, expressed as a whole, does not exceed the quotient of the traction in lbs. per ton divided by twenty, because, when these two are equal, the work of traction and of lighting are equal.

With this system, when cars are descending grades, the motor acts as a dynamo and produces current, which assists to work other cars on the line, so that no power is wasted in grinding and heating brake-blocks. The Author then enters into a careful survey of the conductors and cars necessary to convert the railway from Jersey City to Philadelphia into an electrical railway, using trains of two cars each at ten minutes intervals, and running at a speed of 60 miles per hour.

E. R. D.

Revolving Magnetic Field. By WILFRID DE FONVIELLE.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cix. 1889, p. 732.)

The Author refers to an experiment which he, in conjunction with the late Mr. Lontin, brought before the French Academy in 1880, when they first demonstrated the action of a revolving magnetic-field upon a metallic body suspended so that it can turn freely. Special apparatus was then required, and the present communication shows that rotation can be obtained by the aid of two ordinary Ruhmkorff coils placed either in line or at an angle to each other. A secondary battery is used to supply current to the primary of the first coil whilst its secondary is joined to the secondary of the other coil, the primary of which may be closed or open. If the coils are placed in line rotation is obtained by suspending the metallic body on one or the other side of the common axis of the coils in the intervening space. If the coils are placed at an angle rotation is obtained in all positions. If for the first coil be substituted the current from an alternator the effects are greatly intensified. The Author suggests the employment of a small exploring disk, free to rotate on an axis which can be placed in different positions and at different angles in space, by which lines of force analogous to those of an ordinary or stationary magnetic-field can be discovered.

G. K.

The Magnetic Field in the Jefferson Physical Laboratory.

By R. W. Wilson, Ph. D.

(American Journal of Science, vol. cxxxix. 1890, p. 87.)

This laboratory of the Harvard University has one wing specially constructed throughout of non-magnetic materials, so as to adapt it for delicate magnetic or similar research; in order, therefore, to test the efficacy of these precautions, which have entered into the construction of a building 60 feet square and three floors in height, the Author has carefully determined the variation of the horizontal intensity in the magnetic field over the first-floor, a part of which had been assigned to him for magnetic research. The result shows that the intensity was far from constant; in general, the variation from the mean intensity did not exceed ½ per cent., though in one room, between two neighbouring piers about 6 feet apart, it amounted to 4 per cent. The principal causes of this variation were traced to certain vertical iron pipes outside the building used for warming purposes, and also to an iron stove used for experiments on the floor above. The brick piers, or instrument pedestals, were also found to be sufficiently magnetic to produce the variations otherwise unaccountable.

The Paper is illustrated with plans on which are traced the isodynamic lines, plotted from the actual observations, and also from calculations, in which is introduced the magnetic effect of the iron pipes above mentioned, the intensity and direction of which had been determined by a separate experiment.

F. J.

Determination of the Absolute Thermal Conductivity of Different Rocks. By G. STADLER.

(Neues Jahrbuch für Mineralogie, 1890, vol. i. p. 52.)

The Author has determined the internal thermal conductivity of the following common varieties of rocks, by the method due to H. F. Weber. The results are expressed in absolute measure, using the units gram, centimetre, minute, and Centigrade degree:

k = internal conductivity;
c = specific heat;
ρ = specific gravity.

——	ρ.	c.	k.	$\frac{k}{\rho c}$.
Jura limestone, with much clay	2·590	0·2077	0·3996	0·7428
„ „ with less clay .	2·706	0·2060	0·4849	0·8699
Sandstone, Jura	2·658	0·2061	0·5260	0·9602
Marble, Carrara	2·699	0·2066	0·4900	0·8788
Granite I, Black Forest . . .	2·660	0·1949	0·4545	0·8767
„ II, Baveno	2·596	0·1941	0·5850	1·1610
„ III, Black Forest . . .	2·660	0·1963	0·4881	0·9271
Gneiss, Ossogna Ticino . . .	2·685	0·1947	0·4902	0·9377
Syenite	2·510	0·1986	0·2653	0·5322
Porphyry	2·620	0·1966	0·5013	0·9732
Basalt, middle Rhine. . . .	2·970	0·1988	0·4035	0·6834
Serpentine	2·680	0·2439	0·5037	0·7706
Trachyte, Siebengebirge . .	2·550	0·2089	0·2759	0·5179
Andesite	2·780	0·1993	0·4111	0·7420
Nagelfluhe Conglomerate I, S. Gallen	2·034	0·2071	0·3554	0·8454
„ II „ . .	2·730	0·2107	0·5399	0·9386
Molasse Sandstone I, compact .	2·570	0·2056	0·4882	0·9240
„ II, less compact . .	2·060	0·2010	0·1882	0·4400

H. B.

De Saintignon's Differential Pyrometer. By L. KNAB.

(Le Génie Civil, vol. xvi. 1890, p. 328.)

This instrument determines the temperature of a furnace by exhibiting the rise in temperature of a constant stream of water made to circulate through a copper pipe inserted in the furnace. The Author discusses the objections to the various pyrometers hitherto used for high temperatures, and believes Saintignon's instrument escapes them. It consists briefly of a short copper pipe called the "explorer," which is inserted into the furnace, and into which a stream of water descends from a reservoir through an india-rubber pipe, passing on its way through a filter. From the explorer the water is taken off by another india-rubber pipe to a small glass stand-pipe, from which it is discharged by a cock. The object of the stand-pipe is to enable a constant flow to be maintained by adjusting the cock so as to keep the water-level in the stand-pipe constant. The stand-pipe is graduated so that instead of altering the cock the level may, if preferred, be read off and the proper corrections made. Before and after entering the explorer the water passes around thermometers. If the zero of the second thermometer is made to coincide with the reading of the first, then the desired temperature of the furnace can be read off directly, for with a constant flow of water the rise in temperature for the same instrument is proportional to the difference of temperature of the furnace and of the water, and one experiment will suffice to determine the scale for the second thermometer. To avoid the influence of the furnace walls the explorer should be inserted through an "isolator," which is a tuyere supplied from the same reservoir as the pyrometer. The precautions to be observed in order to obtain correct results are described. The illustration given shows a self-registering form of the apparatus giving a record on paper. The pyrometer may also, by means of a thermo-pile, be made to transmit its indication by electricity to a distance, and exhibit them on a graduated galvanometer.

C. F. F.

On the Method of Conducting Artillery Experiments.

By Captain VALLIER.

(Mémorial de l'Artillerie de la Marine, 1889, p. 329.)

The Author popularizes the formulas of Mr. Tchebycheff relating to the method of interpolation by least squares. He shows how the number of necessary experiments may be reduced by a judicious choice of the points which each should determine, and indicates two distinct rules for guidance in experimenting. The one is to be used when the problem to be solved is itself a function of the variable; the other when it is an integral of such a function.

For the first case, which is of much the most frequent occurrence, he states after Mr. Tchebycheff the equation whose root corresponds with the values which must be given to the independent variable. - He then calculates the resulting equation, which will represent the law sought, from expressions obtained by experience, and shows the advantage of replacing Maclaurin's theorem, between certain defined limits of the variable, by other algebraical expressions which will differ less from the true function within the limits considered. He indicates the applications to be made of these principles in constructing Tables for firing, and the slight modifications necessary in consequence of the difficulty of firing at the very small angles required for precise observations.

D. S. C.

The French Instructions for Firing Coast Batteries.

By Major MILLON D'AILLY DE VERNEUIL.

(**Mémorial de l'Artillerie de la Marine, 1889, p. 249.**)

An instruction issued by the French War Department on the 13th March, 1889, for the guidance of coast batteries in their artillery practice during the year, prescribes, as a test-book, the "Manual for Coast-firing," which was approved by the War Minister on the 23rd of May, 1888. The schools have already tested this manual during the year 1888, and it has been further put to the proof by the Commission. On the practical study of gunnery in their experiments carried out at Toulon in the beginning of the year (1889). The result will probably be that considerable modifications will have to be made in the manual. The probable directions which these modifications will take are discussed by the Author. Of the three methods of finding the range of moving objects, that known as the method of "Circumstance" is practically the only one which a body of troops can employ in accordance with this new order. It is therefore necessary that the artillery schools should study, as far as possible, the best mode of applying this method with the means at their disposal. And yet, this method the Author considers so little removed from chance, that the instructions contained in this manual can scarcely be looked upon as the final solution of the complex and delicate question, What principles should govern the firing of coast batteries? This conviction has led the War Department to zealously pursue the study of this subject, with the result that substantial progress has been made since the beginning of the year (1889).

The Author then examines the question of telemeters, and their present state of advancement, describing the improvements made by Captain Jacomy, upon whose rack-and-pinion elevator the Commission on practical study of gunnery experimented in the previous year.

A plate, illustrating this invention, and several Tables accompany this Paper.

D. S. C.

Smokeless Powder (Experiments made at Essen in July and August, 1889).

(**Revue d'Artillerie, vol. xxxv. 1890, p. 486.**)

These experiments were made to ascertain the ballistic effect of Nobel's powder, as regards maximum pressure and muzzle velocity in four guns, varying in calibre from 5 to 8½ centimetres, that is to say, from 1·968 to 3·317 inches.

The article commences with a description of the powder taken from the specification of Nobel's patent of 31st January, 1888. According to this it is a substance somewhat resembling horn in appearance, composed of nitro-glycerine, nitro-cellulose, and camphor, and is therefore a kind of explosive gelatine with camphor added, and with a considerable preponderance of nitro-cellulose. It may be made into grains of any form, and burns sufficiently slowly as to admit of its use in guns in lieu of ordinary powder, and it possesses the advantages of leaving very little residue and little or no smoke. The object of adding the camphor is to assist the dissolution of the nitro-cellulose, and also to moderate the rapidity of combustion. The proportion of camphor indicated is from 10 to 30 per cent. of the weight of the nitro-glycerine. When nitro-glycerine predominates, it is recommended to make use of a volatile liquid capable of dissolving the nitro-glycerine and the camphor, such as benzol—a compound of carbon and hydrogen represented by the formula $C_{12}H_5H$. When, on the contrary, nitro-cellulose predominates, a liquid such as acetic-ether or acetone is used.

Two methods of preparation are described. In the first method 10 parts by weight of camphor are dissolved in 100 parts of nitro-glycerine to which 200 parts of benzol are added. Into this mixture is introduced 50 parts of dried pulp of soluble gun-cotton. The benzol is then evaporated, and the materials thoroughly mixed by passing them between two hollow cylinders heated by steam to a temperature of 110° to 140° Fahrenheit. When the mixture is sufficiently homogeneous it is moulded into grains or rolled out into sheets, which are afterwards cut up into grains or pellets ready for use.

The other method is as follows:—Mix together 100 parts of nitro-glycerine, 10 to 25 parts of camphor, and 200 to 400 parts of acetate of amyl (a compound represented by the formula $C_{10}H_{11}O, C_4H_3O_3$). Into this put 200 parts of dry pulp of soluble gun-cotton. This mixture is kneaded until the gun-cotton is completely dissolved. The pasty matter thus obtained is reduced into thin sheets from which the moisture is expelled by heat, and the dry material is formed into grains or pellets fit for use.

The article then refers to a second Patent of Mr. Nobel, dated 26th March, 1889, in which there is no mention of camphor. The essential elements are as before, nitro-glycerine and nitro-cellulose, with the addition of nitrated starch, or of nitrated dextrine, and a certain quantity of the nitrate chlorate or picrate of some alkali in powder.

The article then proceeds to give an account of experiments made at Essen with the Nobel powder in August, 1889. The powder used was composed of a mixture in equal proportions of nitro-glycerine and nitro-cellulose kneaded together and made into cubical grains.

Experiments were made with cubical grains of four dimensions, viz., 0·1181, 0·1378, 0·1575, and 0·1969 inch of a side, as previous to these experiments nothing was known either as to the best weight of charge or the size of grain suitable to the calibre of the guns. The guns used on the experiments were as follows :—

No. 1—calibre, 1·968 inches; length of bore, 40 calibres; weight, 490 lbs.
„ 2 „ 2·362 „ „ 40 „ „ 862 „
„ 3 „ 2·952 „ „ 28 „ „ 904 „
„ 4 „ 3·317 „ „ 40 „ „ 2,310 „

The results are given in the following Table :—

Description of Gun.	Date.	No. of Round.	Charge.	Size of Grain.	Projectile.	Velocity at 110 feet from Muzzle.	Maximum Pressure.
			Lbs.	Inch.	Lbs.	Feet per Second.	Tons per Sq. In.
No. 1	13 July, 1889	1	0·66	0·1378	3·81	1,886	8·461
„	„	2	0·77	0·1378	3·81	2,089	8·955
„	„	3	0·80	0·1378	3·81	2,171	13·23
„	7 Aug., 1889	1	0·66	0·1181	4·07	1,798	9·713
„	„	2	0·77	0·1181	4·10	2,014	11·33
„	„	3	0·792	0·1181	4·10	Mean 2,070	13·01
„	„	4	0·792	0·1181	4·10		12·28
„	„	5	0·792	0·1181	4·10		13·80
No. 2	5 Aug., 1889	1	0·66	0·1181	6·84	1,109	3·152
„	„	2	1·10	0·1969	6·84	1,637	6·895
„	„	3	1·21	0·1969	6·84	1,758	8·603
„	„	4	1·10	0·1575	6·86	1,811	9·522
„	„	5	1·00	0·1181	6·86	1,860	10·180
„	„	6	1·10	0·1181	6·86	2,043	12·48
No. 3	12–13 Aug. 1889	1	0·66	0·1181	15·0	1,086	5·762
„	„	2	0·77	0·1181	15·0	1,188	7·078
„	„	3	0·88	0·1181	15·0	1,283	8·593
„	„	4	1·00	0·1181	15·0	1,404	10·24
„	„	5	1·10	0·1181	15·0	1,512	12·28
„	„	6	1·17	0·1181	15·0	1,588	13·56
„	„	7[1]	1·00	0·1181	15·0	1,424	10·44
„	„	8[1]	1·00	0·1181	15·0	1,424	10·50
„	„	9	1·10	0·1181	15·0	1,522	12·41
„	„	10	1·17	0·1181	15·0	1,594	12·31
No. 4	5 Aug., 1889	1	2·20	0·1969	15·41	1,607	5·33
„	„	2	2·64	0·1969	15·50	1,883	8·43
„	„	3	3·08	0·1969	15·50	2,004	9·02
„	„	4	3·30	0·1969	15·50	2,136	9·25
„	„	5	3·52	0·1969	15·50	2,239	11·20
„	„	6	3·74	0·1969	15·50	2,336	11·69
„	6 Aug., 1889	1	3·30	0·1575	15·50	2,316	13·97
„	„	2	3·54	0·1575	15·60	2,324	13·83
„	„	3	3·30	0·1575	17·84	Mean 2,231	13·24
„	„	4	3·30	0·1575	17·84		13·70
„	„	5	3·30	0·1181	17·84		13·24
„	„	6	2·86	0·1181	17·84	Mean 2,168	14·61
„	„	7	2·86	0·1181	17·84		14·09

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[1] The powder in rounds 7 and 8 had been previously put into water for thirty minutes and then dried at a temperature of 86° Fahrenheit.

J. A. L.

Mesuré and Nouel's Pyrometric Telescope.

(L'Industrie Moderne, 1890, p. 13, 2 Figs.)

This is a telescope for the purpose of rapidly estimating the temperature of incandescent bodies, and was made by Mr. Ducretet, of Paris. It is well known that it is absolutely necessary to estimate the heat of ovens for baking china, glass furnaces and those used in making steel, and for this purpose many kinds of pyrometers have been used. Pouillet has given a scale of colours corresponding to different temperatures, but in many cases it is impossible to judge of temperature from observation of colour, owing to the want of a standard for comparison. The photometric methods of Messrs. Crova, Trannin and Violle are suitable only for laboratory use. The pyrometric telescope, however, is perfectly portable, and allows the temperature to be ascertained by showing at a glance the exact colour of the heated body. The inventors, Messrs. Mesuré & Nouel, are engineers at the St. Jacques branch at Montluçon of the Compagnie des Forges de Châtillon-Commentry.

The apparatus depends upon the principle of rotary polarisation, and contains two Nicol prisms; the one acting as a polariser, the other as analyser, and so placed as to have their principal sections at right angles to one another. Between the two prisms is placed a plate of quartz. It is well known that a luminous ray is polarised in a definite plane by the principal section of the polarising prism, and is extinguished by traversing the principal section of the analyser. The plate of quartz, which is interposed perpendicularly to the axis, causes the plane of polarisation to turn, so that it becomes oblique upon the principal section of the analyser, and then traverses it without being totally extinguished. According to Biot's law, the angle of deviation is proportional to the thickness of the quartz and almost inversely proportional to the square of the wave-length of the light. As the wave-length varies with the colour, which itself depends upon the respective proportion of simple rays in the ordinary ray of transmitted light, it is seen that the observed deviation will depend directly upon the colour of the ordinary ray, and if there is a method of measuring such deviation the temperature will be known from the colour of the incandescent body. For this purpose, the analyser is movable inside the telescope, so that it can be placed at any angle with the polariser. By means of a pointer the angle of deviation can be read upon a dial, where zero corresponds to complete extinction, the quartz being lifted.

If the incandescent body be looked at with the telescope while the analyser is slowly turned, the light is seen of a certain tint determined by the heat of the body, and this tint will disappear for a certain angle of rotation; this angle then acts as a measure of the temperature.

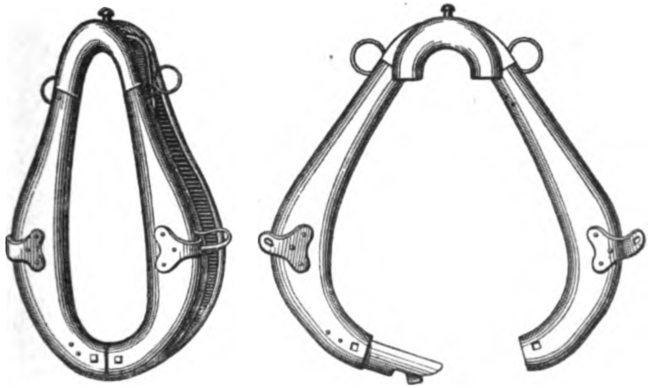
In practice, a well-defined tint is observed which may easily be distinguished, then it is found that, for a slight movement of the analyser, the tint changes quickly from green to red, and between these two colours a passing shade of "dull lemon" is seen. To this well-defined shade are referred the angles measured. The instrument contains three lenses, two of which collect the rays for the polariser, the third, which is placed in the eye-piece, collects them from the analyser, and is revolved with it. A scale is provided for the purpose of enabling the observer to regulate the distance apart of the lenses by closing or opening the telescope according to the distance of the incandescent object. It is in constant use at the St. Jacques works previously referred to, and has given good results.

E. R. D.

Metal Horse-Collar. By L. Knab.

(La Nature, 5 April, 1890, p. 279.)

After enumerating the various disadvantages of the leather collar generally used, the Author describes a new elastic collar made of sheet-steel, now being tried by the Paris General Omnibus Company. The plates are of the best quality of metal obtainable, and are stamped and moulded into the form shown in the Figs. by special presses designed by the inventor. All the parts are exactly fashioned, and are interchangeable. The conformation of that part of the collar in contact with the horse's shoulders has been the result of "profound anatomical study" on the part of the inventor. The surfaces are galvanized; their greasy polish, rounded contours, and incapability of distortion, render all galling impossible. The curved form of the metal sides gives great strength,



and at the same time lightness and a certain amount of elasticity, which deadens the shocks arising from sudden and violent effort. The facility afforded for opening and closing the collar effects a notable saving of time; while the large surface bearing against the shoulders, and the certainty of no sores resulting to its use, conjoined to its cheapness, secure to this collar important advantages. Lastly, the same pattern will fit several horses.

F. G. D.

On Uniform Time for Germany. By — STRECKERT.

(Glaser's Annalen, No. 297, Nov. 1, 1889, p. 183.)

At the meeting of the Verein für Eisenbahnkunde, on October 8th, the question of the adoption of uniform time on all German railways was discussed. The Author stated that this matter has been under consideration for upwards of five years, and that, though each different State had originally used its own system of time-reckoning, about six years ago, in consequence of a movement in favour of introducing Berlin time, this was now adopted over about 22,500 kilometres of railway. Purely scientific men were attempting to establish uniform time throughout the world by the adoption of an initial meridian (that of Greenwich) which would point to the introduction of the 15th degree of longitude east of Greenwich for Germany, which actually falls, at Stargard, six minutes of time east of Berlin. The Conference of Rome made the day to date from mean noon at Greenwich, and the time was to be counted from 0 to 24 hours. In the Conference at Washington, in 1884, sundry modifications were discussed, but prior to this, at the conference on general time at St. Louis, in April 1883, a convention for all the States of America adopted a system of five zones of 15°, each of which was to represent an hour of time; thus 60° west of Greenwich begins at 4 o'clock inter-colonial time, 75° eastern time 5 o'clock, 90° central time 6 o'clock, 105° mountain time 7 o'clock, and 120° Pacific time 8 o'clock. These five meridians were introduced on all American railways in 1885, and they have since become the universal system of reckoning time throughout the United States. Sweden and Japan have likewise agreed to a uniform system of reckoning time, Sweden adopting the meridian 15° east of Greenwich as the standard time for the whole country, the change taking place at midnight on December 1st, 1878, and Japan selecting 135° east of Greenwich for the whole empire on January 1st, 1878. This time would join on with that of America, and give 15 o'clock west of Greenwich. The railway authorities of Austria and Hungary have petitioned the Government to establish uniform time throughout their system based on the 15° east of Greenwich, and the Government assent is conditionally granted, on the understanding that the German railways will fall in with the system.

France has so far adopted Paris time, and a proposal is under consideration by the Government to make Paris time the standard for the whole country and for Algeria. The Author names three zones which might embrace the whole of Europe:—Greenwich time, Meridian 0, for England, Ireland, France, Holland, Belgium, Spain, and Portugal; Meridian 15° east of Greenwich, for Norway, Sweden, Denmark, Germany, Austria, Switzerland, Italy and Servia; Meridian 30° for European Russia, Roumania, Bulgaria, Turkey-in-Europe, and Greece. After full discussion, the following resolutions were proposed:—The Verein für Eisenbahnkunde in Berlin considers the introduction of a normal time reckoning (uniform time) for the internal and external service of railways, to be extremely desirable in the interests of regular and safe working, and herewith recommends the mean solar time for the earth's meridian lying 15° of longitude to the eastward of Greenwich Observatory. The Verein is further of the opinion that the introduction of this time-reckoning into Germany would be of advantage in respect to juristic and civic proceedings, and could readily be accomplished, as has been done in England, Sweden, North America, and Japan. This resolution was unanimously adopted by the meeting, and copies were directed to be sent to the Chancellor and to the authorities of the various States.

G. R. R.

Speed-Trials of Fast Ships.

By Assistant Engineers Harold P. Norton and Walter M. McFarlane, U.S. Navy.

(Journal of the American Society of Naval Engineers, 1890, p. 68.)

Four methods of measuring the speed of a vessel upon a trial-trip are discussed by the Authors.

1st. By readings of patent logs.

2nd. By successive runs in opposite directions over a measured base.

3rd. By a continuous run at sea, the speed being based on the number of revolutions of the screw found necessary to give a knot in smooth water.

4th. By a continuous run at sea past a series of buoys, or stations on shore, so arranged as to give the distance that the ship is likely to make, provision being made for accurate determination of the strength of tide and current at frequent intervals along the course.

Although the first method has the advantage of simplicity, it is condemned as entirely untrustworthy. Proof of its failure is afforded by a Table of the speed-records of the s.s. "H. F. Dimock," as taken by two patent logs. The trials were made by the Navy Department in 1885. Readings were taken simultaneously when passing lighthouses or prominent land-marks, and a comparison of the distances between the various landmarks as given by the two logs shows that they not only differ from each other, but that each log varies most peculiarly itself. The Authors proceed to consider what is the best length of base for the second method of measurement, and conclude that a course of one knot is to be preferred, because the change in the velocity of the tide can be neutralized when the intervals between the opposite runs are short, whereas in a course of 10 knots, which had been proposed, the intervals would be so long that the change in velocity of the tide would introduce very appreciable error. It is pointed out that in the trial of a fast vessel upon a base of a measured mile, the determination of the time on the course is of the most vital importance. Stop-watches as usually made read only to one-fifth of a second, and the Authors do not consider that sufficiently accurate, because in a trip of 19¼ knots speed, an error of one-fifth of a second involves an error of $\frac{1}{200}$ of a knot. They remark that the turns at the end of the mile appear to throw a much greater stress on the machinery than is experienced when the vessel is on a straight course.

If the third method be chosen, it is necessary to determine the number of revolutions per minute and per mile for various speeds in smooth water, by runs in opposite directions over a measured knot. The depth of water for large vessels should not be less than 19 fathoms. Several sets of runs should be made at different speeds; at least four, and preferably six runs at each speed. The Authors suggest that in the case of a vessel whose maximum speed is 19 knots, runs should be made at 14, 16, 18 and 19 knots, or as near to the latter speed as the contractors are willing to go on a preliminary trial. The revolutions must be counted with the greatest accuracy, and curves plotted on a large scale, showing revolutions per minute and per mile, with the speeds for abscissas, so that speeds to a hundredth of a knot can be determined. The Authors think that the curves may be safely produced to include a speed higher than those plotted, if on the final trial they should be exceeded. On the continuous trial, which should be of four hours' duration, mean readings from two counters attached to each shaft should be taken every ten minutes. The total number of revolutions made in the four hours being determined, the average revolutions per minute can be obtained, and from them the number per mile, and the speed of the vessel.

For the fourth method it is necessary to station tugs, or other small vessels, along a course of 80 or 100 miles, with competent observers and apparatus on board for the accurate determination of the strength of the tide and currents at various points. The observations should include currents below the surface, if any exist, or if their strength be different from that on the surface. Unless the buoys are very close together, it will be necessary, as the end of the four hours' period approaches, to take sextant angles of the beacons or buoys, so that the position can be accurately plotted from time to time, and be readily determined when the end of the trial occurs. The distance traversed as thus found must be corrected for the force of tide and current, and the average speed computed. The cost of establishing the course, and of making the necessary tidal and current measurements, together with the large number of observers required, are urged as serious objections.

The Authors favour the third method, and are of opinion that by using a chronograph which will read accurately to the tenth of a second, and revolution counters of which the error will be less than one revolution, sufficient accuracy may be obtained.

S. W. B.

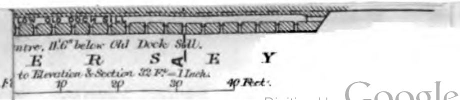
INDEX

TO THE

MINUTES OF PROCEEDINGS,

1889-90.—PART II.

LONDON: PRINTED BY WILLIAM CLOWES AND SONS, LIMITED, STAMFORD STR
AND CHARING CROSS.


ntre, 11'6" below Old Dock Sill.
E R S E Y
to Elevation & Section 32 Ft = 1 Inch.
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20
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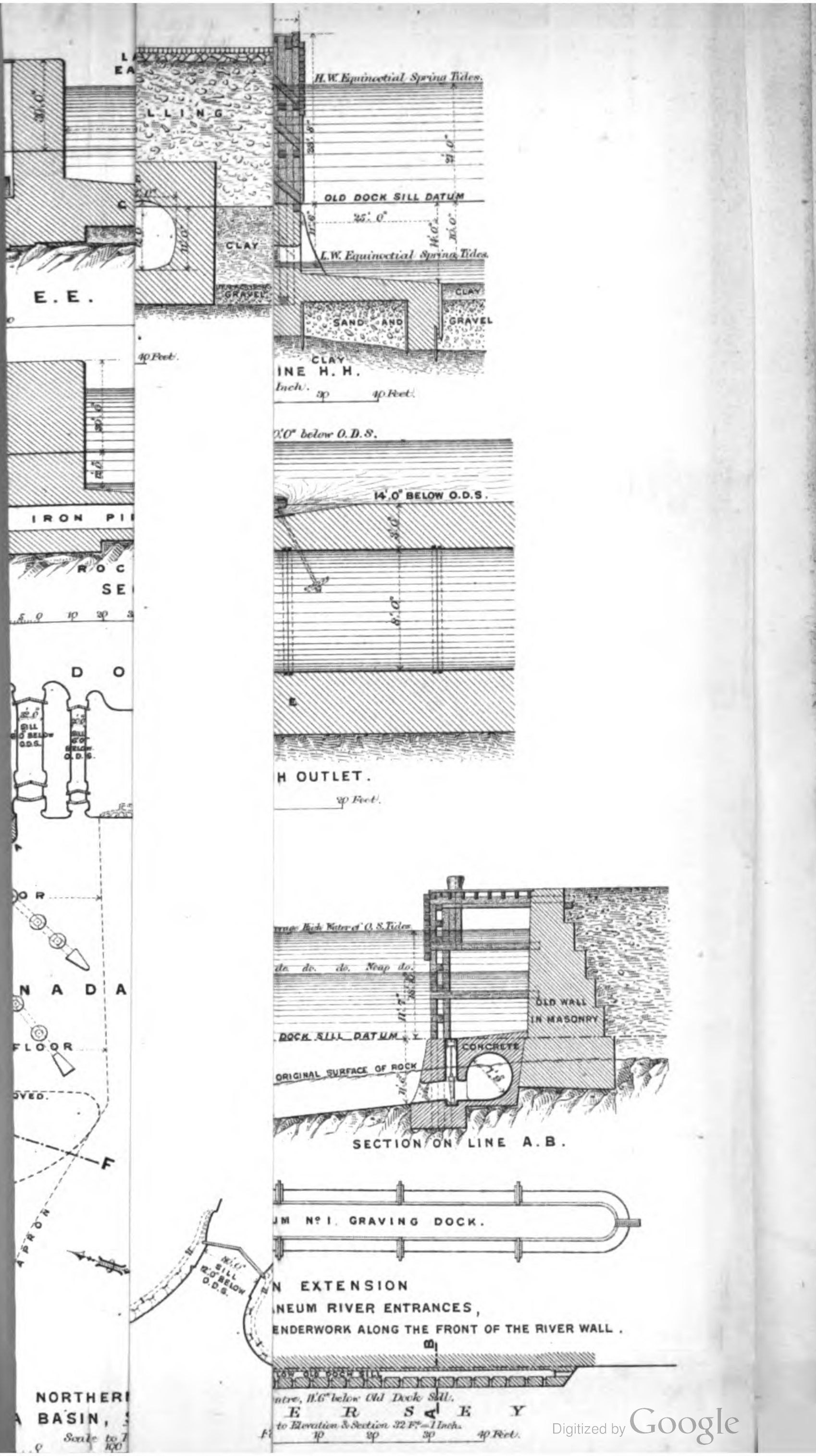
40 Feet.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33.0"
OLD DOCK SILL DATUM
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14.0"
10.0"
12.0"
CLAY
L.W. Equinoctial Spring Tides.
GRAVEL
CLAY
SAND AND GRAVEL
CLAY
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.0" below O.D.S.
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SILL 6.0" BELOW O.D.S.
OR
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OVED.
F
APRON
12.0" SILL 12.0" BELOW O.D.S.
B
A
Average High Water of O. S. Tides
do. do. do. Neap do.
11.7"
DOCK SILL DATUM
OLD WALL IN MASONRY
CONCRETE
ORIGINAL SURFACE OF ROCK
SECTION ON LINE A.B.
UM No 1. GRAVING DOCK.
NORTHERN
N EXTENSION
A BASIN,
ANEUM RIVER ENTRANCES,
ENDERWORK ALONG THE FRONT OF THE RIVER WALL.
LOW OLD DOCK SILL
ntre, 11.6" below Old Dock Sill.
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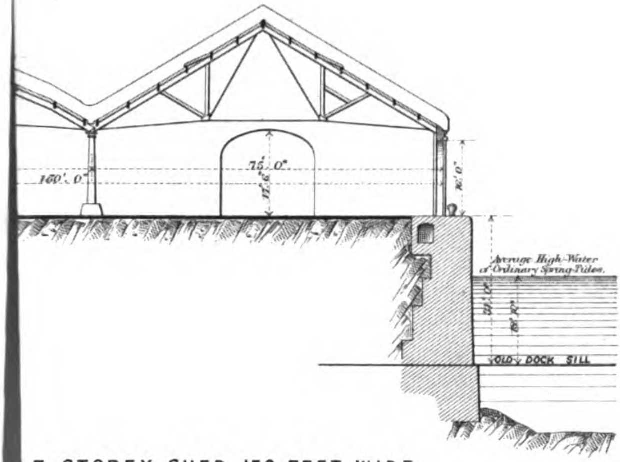
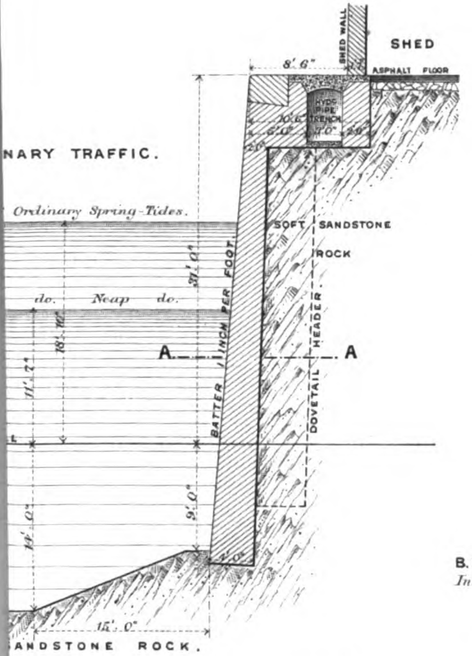
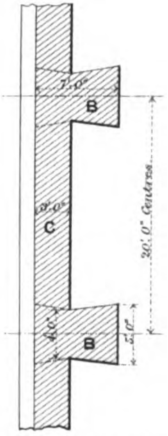
Scale to P
to Elevation & Section 32 Ft. = 1 Inch.
0 100
10 20 30 40 Feet.



LE STOREY SHED 150 FEET WIDE.



HERCULANEUM DOCK
MASONRY FACING TO SANDSTONE ROCK.

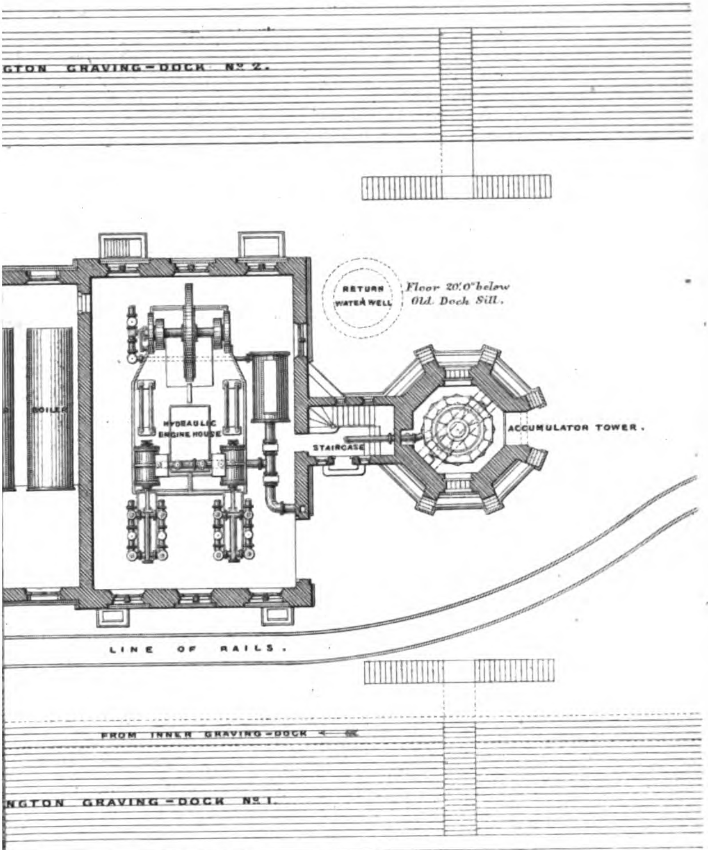


B.B. *Dovetail Headers to retain Intervening Masonry Panel* C.

PLAN AT A.A.

THOS KELL & SON, LITH 40 KING ST COVENT GARDEN

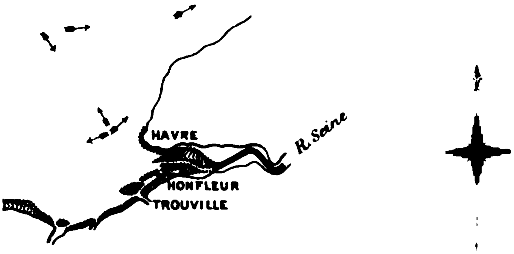
PLATE . 4.



N .

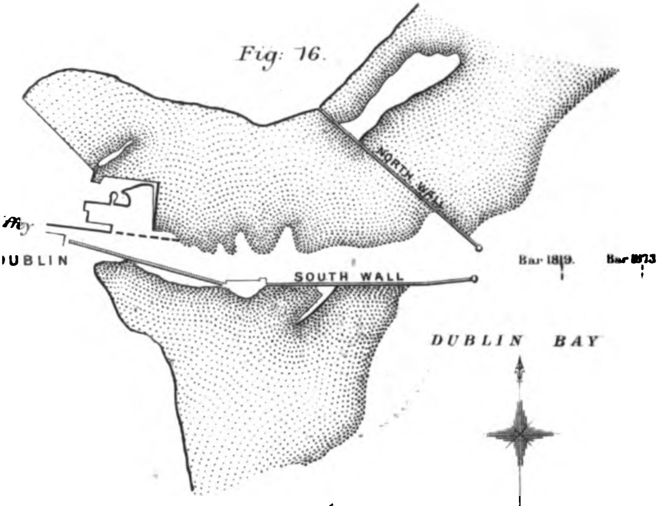
THOS KELL & SON, LITH. 40, KING ST COVENT GARDEN.

6.



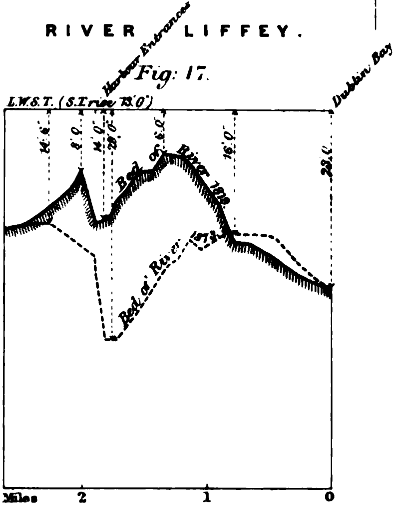
R SEINE.

Fig: 16.



RIVER LIFFEY.

Fig: 17.



SECTION OF BAR OF LIFFEY.

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SHA

PLATE. 6.

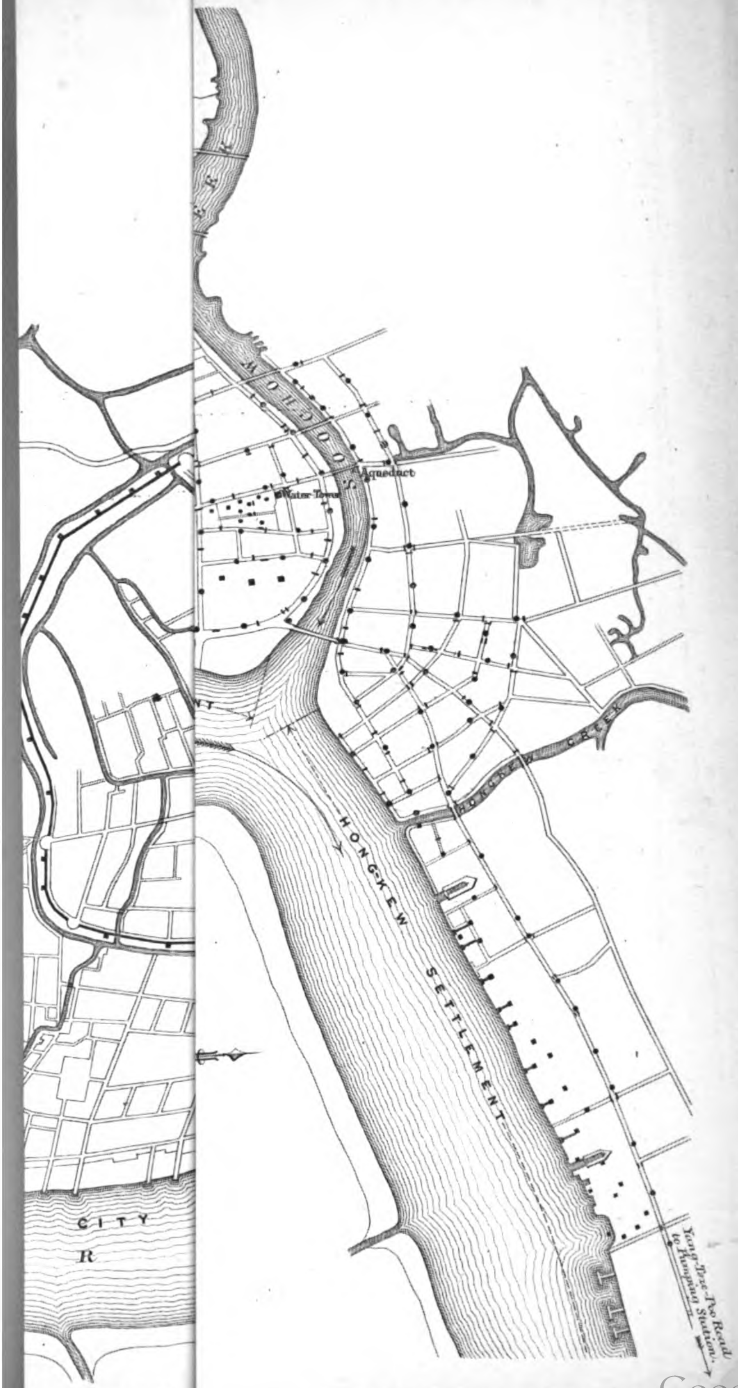

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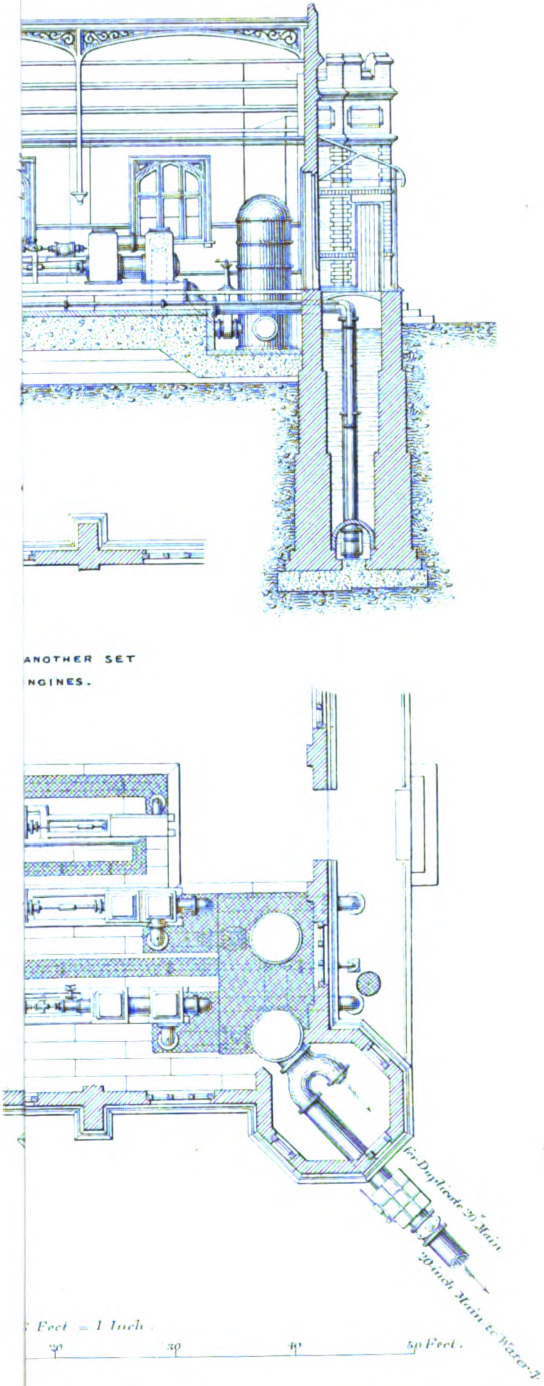
PLATE. 7.



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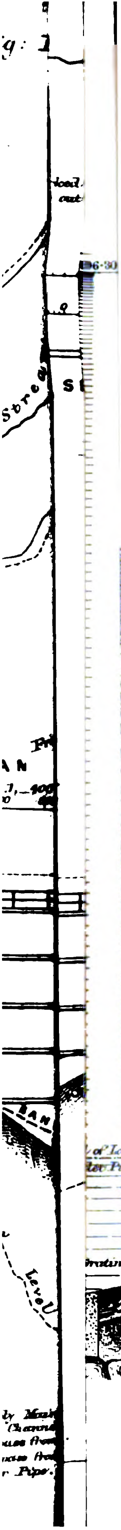
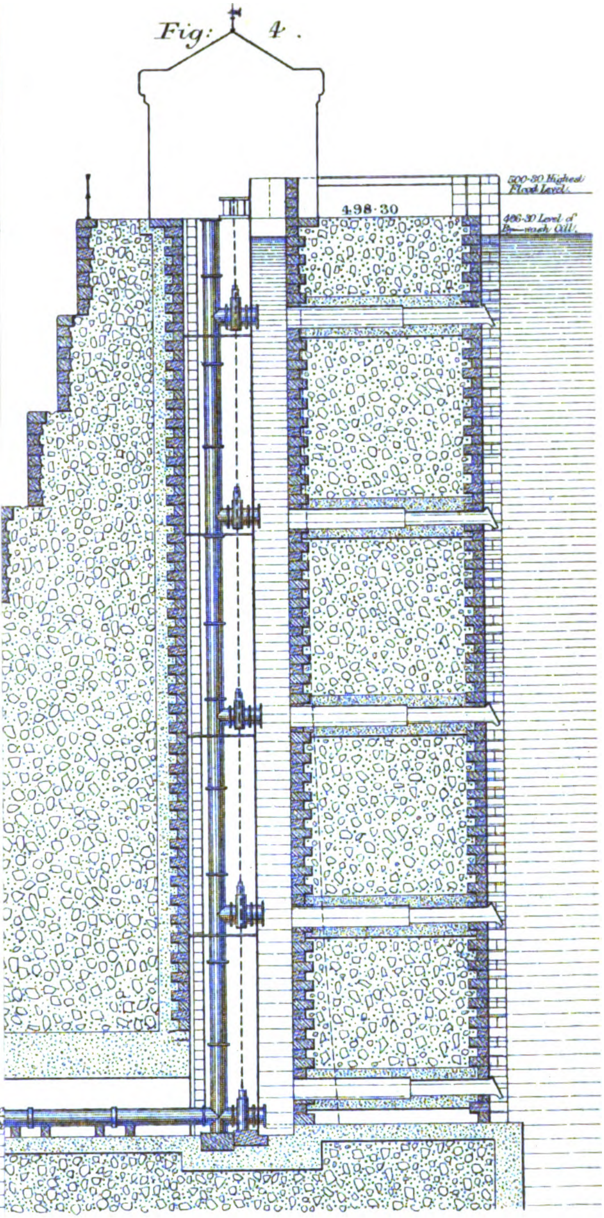




ION THROUGH VALVE-WELL.

4_ 20 Feet = 1 Inch.

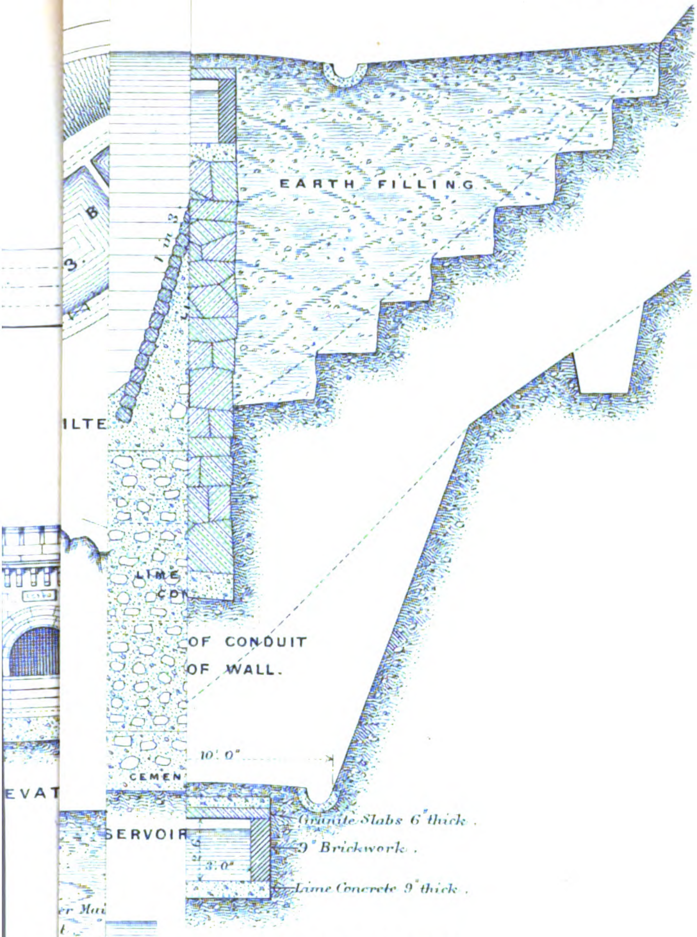
30 40 50 60 70 Feet

7_ 16 Feet = 1 Inch.

20 30 40 50 Feet

8_ 8 Feet = 1 Inch.

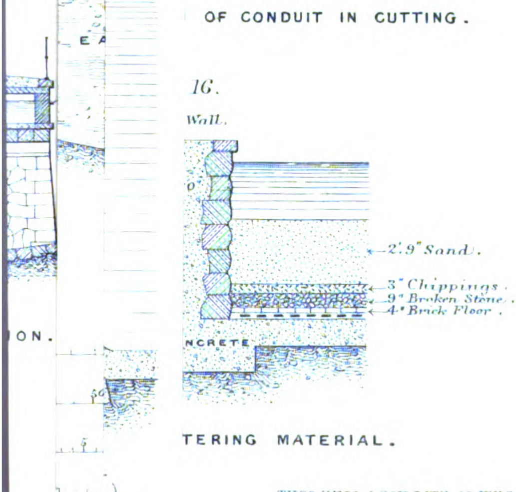
0 10 Feet.



OF CONDUIT IN CUTTING.

16.

Wall.



TERING MATERIAL.

lings.)

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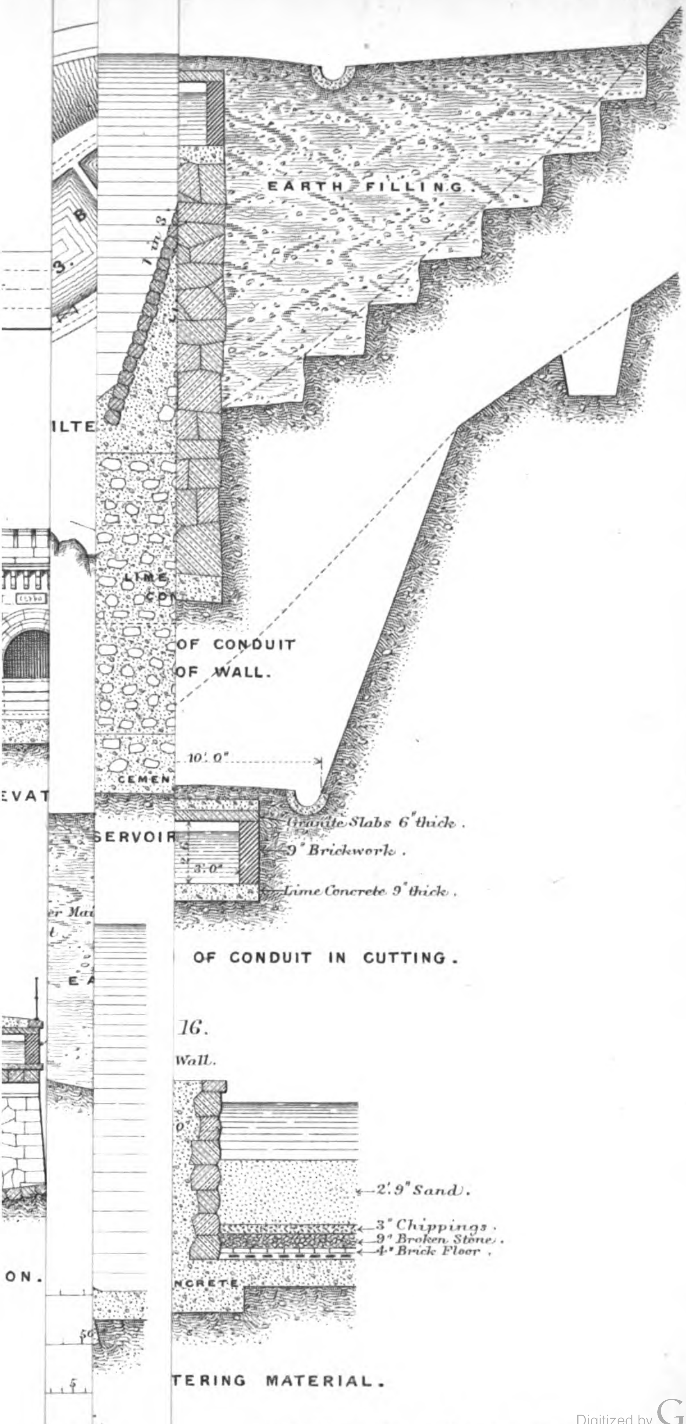

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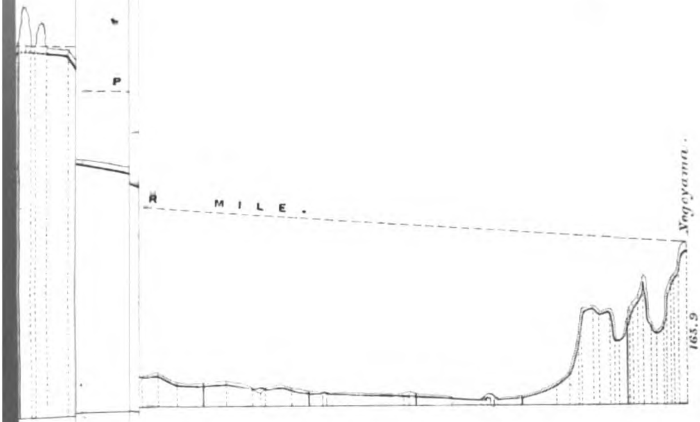
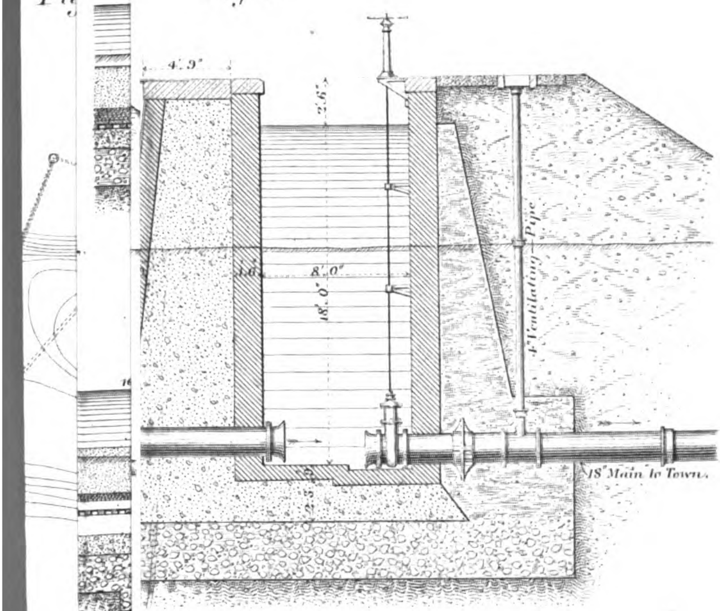
PLATE .10.



Fi

Fig: 9.



ICE- ON OF OUTLET-WELL TO RESERVOIR.

Sc
190

f Prc

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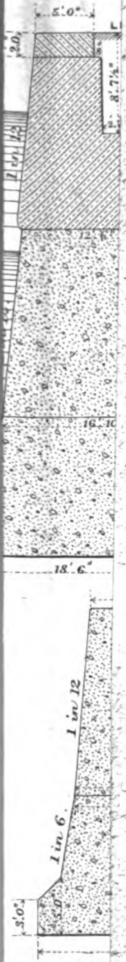
Fig : 6.



SEC

Fig : 8

s.

Instr.

Wire

PLATE . 12 .

Fig : [illegible]

Fig : 13.

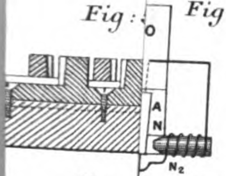


Fig : 6

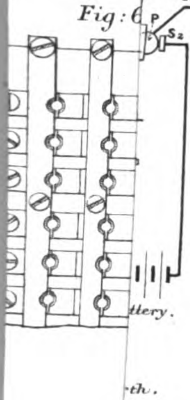


Fig : 17.

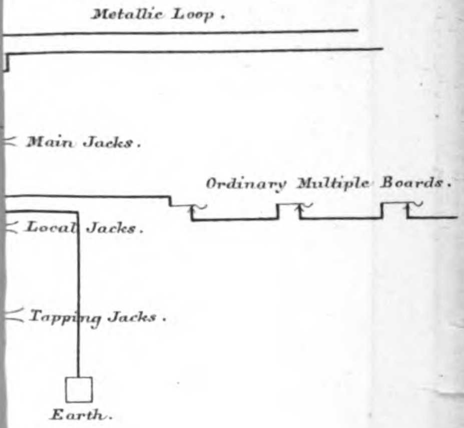


Fig : 16.

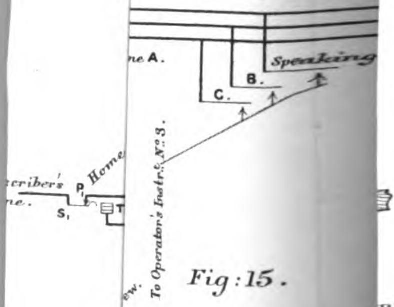
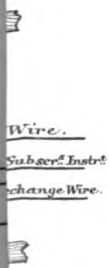
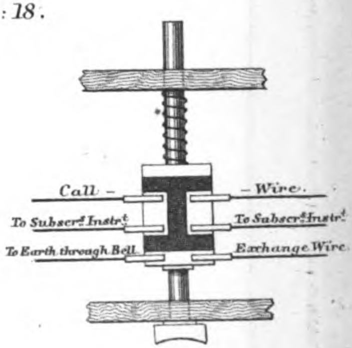


Fig : 15.



UBSCRIBER.

Fig : 18.



SPEAKING TO EXCHANGE.

-90. Part II.

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