International Engineering Congress,
GLASGOW, 1901.

SECTION II.

WATERWAYS AND MARITIME WORKS.

PROCEEDINGS.

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XXX

International Engineering Congress,

GLASGOW, 1901.

MEETING

HELD AT

THE UNIVERSITY, GLASGOW,

ON THE

3rd, 4th and 5th SEPTEMBER, 1901.

PROCEEDINGS OF SECTION II.

WATERWAYS AND MARITIME WORKS.

F. Nr. 24473

Königl. Ministerium der öffentlichen Arbeiten Bibliothek

LONDON:

WILLIAM CLOWES AND SONS, LIMITED,

32, COCKSPUR STREET, S.W.

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BIBLIOTEKA KRAKÓW Politechniczna

INTERNATIONAL ENGINEERING CONGRESS,

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INTERNATIONAL ENGINEERING CONGRESS,

GLASGOW, 1901.

PROCEEDINGS OF SECTION II.

PREFACE.

In presenting this record of the Proceedings of Section II., my first duty is to acknowledge, with grateful thanks, how much the Section is indebted to the foreign engineers who so cordially responded to my appeal for their co-operation in rendering our proceedings truly international in character.

Out of the fourteen Papers presented for discussion, six were contributed by Continental engineers, from France, Germany, Russia, Spain, Belgium, and Roumania, and two by our engineering brethren in the United States; whilst of the remaining six, by British engineers, two dealt with works carried out in Egypt and China, two were devoted to the improvement works of the Clyde and its estuary which have given Glasgow its commanding commercial importance, and one related to the lighting of the Scottish coasts. As Herr Hermann's Paper was written in German, and the three Papers by MM. Quinette de Rochemont, de Timonoff, and Nyssens Hart and Van Gansberghe in French, I obtained the assistance of Mr. L. L. Kropf for the translation of the first, and of Mr. Lucien Serraillier for the translation of the three French Papers; and Mr. Serraillier has also assisted me in the editing of the Papers and discussions for publication, and in the compilation of the index to the Proceedings, having also rendered the same services in the preparation of the Proceedings of Section I.

Most of the foreign Authors, namely, MM. de Churruca, Hermann, Quinette de Rochemont, de Timonoff, and Van Gansberghe, conferred a further kindness on the Section by coming over specially to attend the meetings of the Section, so as to be enabled to furnish additional information on the subjects of their Papers, and to reply to the discussion; whilst Mr. Harding was present from China, and Mr. Willcocks, of Cairo, was only prevented from attending by being summoned to South Africa for a special investigation of schemes for irrigation in the Transvaal and Orange River Colony. For the information of those who did not attend the Congress, it may be mentioned that in Section II., in accordance with the usual custom at Congresses abroad, each Paper, having been previously printed and distributed, was introduced by merely a short summary of the principal points contained in it, given by the Author, or, in his absence or at his request, by the Honorary Secretary, thereby allowing considerably more time for the discussion of the important questions raised in the Papers.

The publication in full of the Papers and discussions on them, in both Sections I. and II., has been rendered possible by the very generous contribution of £500 by the Institution of Civil Engineers, through the Council, towards defraying the expenses involved; and, consequently, the cordial thanks of all the members of these two Sections are due to the Council of the Institution of Civil Engineers, for thus securing the preservation of permanent records of the Proceedings of the two Sections in a form which, it is hoped, will be valuable for reference.

The thanks also of the members of Sections I. and II. are most particularly due to the energetic organisers and the Local Executive Committee of the Glasgow International Engineering Congress, for having given railway and hydraulic engineers such an excellent opportunity of collecting together the large quantity of very valuable information contained in the Papers, and of interchanging views with one another and with their foreign brethren in the discussions on the important subjects presented for their consideration; and also for the generous co-operation of the Glasgow authorities with the Institution of Civil Engineers in the publication of the two volumes containing the Proceedings of the two Sections.

L. F. VERNON-HARCOURT,

Honorary Secretary of Section II.

6, Queen Anne's Gate,
Westminster, S.W.

February, 1902.

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SIR JOHN WOLFE BARRY, K.C.B., LL.D., F.R.S.,
Past President of the Inst.C.E.

Vice-Chairman:

WILLIAM H. HUNTER, M.Inst.C.E.

Honorary Secretary:

L. F. VERNON-HARCOURT, M.A., M.Inst.C.E.

PROCEEDINGS OF SEPTEMBER 3.

Sir JOHN WOLFE BARRY, K.C.B., LL.D., F.R.S., in the Chair.

The CHAIRMAN: It is quite unnecessary for me as Chairman of this Section to make any introductory remarks, but I hope I may be allowed to say how cordially the British representatives of engineering welcome their *confrères* from every part of the world. I think I may claim that Section II. is one of the most truly international sections which could be allocated to engineering work. The work we, who are interested in this Section, do in the improvements of harbours, canals, and rivers, in irrigation, and in other kindred matters, appears to me to be, perhaps, more world-wide and less patriotically local than any of the work of the other sections which form part of this Congress. I am, therefore, extremely happy to be allowed the privilege of presiding over this Section.

My particular work in engineering has been to some extent of the nature which I have indicated, and I think we may claim that the Papers which will be submitted to this Section are truly representative ones, consisting as they do to-day of a most interesting Paper on a canal which appears to have an international interest, of a treatise of a most valuable nature on the use of excavating tools and machinery applicable to engineering work in all parts of the globe, and lastly of a Paper on the irrigation of the great Nile Valley; I think these three Papers will make a very good commencement to the work of this Section.

[Paper.]

THE DORTMUND AND EMS CANAL.

By Herr Regierungs-und Baurath Hermann.

Historical.—The Dortmund and Ems Canal owes its origin to the continuous efforts made, ever since the middle of last century, to connect the industrial centres in Rhineland and Westphalia with Eastern Prussia by means of a waterway. The complete realisation of this idea, namely, to establish a continuous waterway from the Rhine to the Weser, Elbe, Oder, and Vistula, forms part of the extensive canal scheme which is at present awaiting the sanction of the Prussian Diet.

The Dortmund and Ems Canal, in its present form, constitutes a portion of the large waterway which, in the near future, is destined to connect the Rhine with the Elbe. From one of its extreme ends at Herne, a canal is to be carried on to form a junction with the Rhine; and from Bevergern another canal is to be made until the Elbe is reached. So long as the junctions with the Rhine and Elbe remain unfinished, the Dortmund and Ems Canal forms a connecting link between the country served by it and the trade of the world by way of Emden and the North Sea. Such a connecting link by means of a waterway is necessary, because in the busy industrial region of Rhineland and Westphalia there exists a steadily growing traffic, with which the railways in their present developed state have hitherto been able to cope; but it is doubtful whether they will be able to do so in the future. It has also been found necessary to reduce the cost of carriage by the creation of a waterway, to assist the industry of Rhineland and Westphalia in its competition with the foreign and home trades. The region of this industry occupies a narrow strip of land between the Lippe and the Ruhr, extending from the Rhine to as far as Unna, its area being about 3,600 square kilometres (1,390 square miles). Although this area only represents about $\frac{1}{150}$ part of Germany, the amount of its railway traffic represents one-quarter of that of the whole of Germany, that is—to enable a comparison to be made—about the eighth part of the railway traffic of England. The coal and iron trades supply the great bulk of this traffic. At the present day there are one hundred and seventy collieries at work within the limits in question, with a yearly output of over 54,000,000 tons and employing 205,000 men. Assuming that shafts are sunk to a depth of 700 metres (2,300 feet), there is an ample supply of coal for 200 years, even if a considerable increase should take place in the yearly output; and there is enough coal for 300 years if the shafts are sunk to a depth of 1,000 metres (3,280 feet). The number of large ironworks exceeds one hundred at the present day. The Dortmund and Ems Canal penetrates into this region as far as Dortmund and Herne.

Route of Canal.

(Figs. 1 and 2.)

The law of 9th July, 1886, which sanctioned the construction of the canal, fixed Dortmund for its starting point, and that it should pass by Münster, Bevergern, and Papenburg on its route. Beyond this last-named place the canal was to follow the course of the Lower Ems, and a lateral canal from Oldersum was to lead as far as the inland port of Emden. The distance from Dortmund to Emden, measured along the canal, is 270 kilometres (168 miles). The branch from the main canal to Herne is about 11 kilometres (7 miles) long. The object of the lateral canal, from Oldersum to Emden, was to skirt the widening estuary of the Ems above Emden, where the navigation with canal boats is liable to be difficult. Moreover, this extension makes the canal traffic between Emden and Oldersum independent of the state of the tide.

The summit level of the Dortmund and Ems Canal between Dortmund and the canal-lift at Henrichenburg is 15·3 kilometres (9½ miles) long, and its water-level is 70 metres (230 feet) above zero.* From this reach the barges are lowered by the lift to 56 metres (184 feet) above zero into the main reach below, which runs from Herne to Münster, and is 67 kilometres (41⅗ miles) long. At the latter place there is a lock with a fall of 6·2 metres (20⅓ feet) into the Midland reach, which is 36·8 kilometres (nearly 23 miles) long, and its water level 49·80 m. (164 feet) above zero. The future extensions, connecting the present canal with the Weser and Elbe, will start from the termination of this Midland reach.

In determining the route and the levels of the Dortmund and Ems Canal, possible future extensions of the system were carefully studied from the outset. When, therefore, the canal leading to the Elbe is eventually carried out, according to pre-arranged plans, there will be a reach of 210 kilometres (130½ miles), from Münster to Hanover, without a single lock. From the Midland reach the canal descends to the Ems by locks, with falls varying from 4·10 to 3·36 metres (13½ feet to 11 feet). The last lock leading into the Ems at Gleesen has a fall of 6·20 m. (20⅓ feet), and is built with side ponds like the lock at Münster, which has the same fall. Down to this point all locks have an available length of 67 metres (220 feet), an entrance width of 8·6 metres (28¼ feet), and a depth of water of 3 metres (10 feet) on the sill.

Beyond the Gleesen lock the canal follows the River Ems for a distance of about 1·5 kilometres (about a mile). Next it joins the Haneken Canal by means of a regulating lock (*Sperrschleuse*) at Haneken Ferry, which was constructed by the Hanoverian Government in 1825 for the canalisation of the Ems. This canal is 25·65 kilometres (nearly 16 miles) long, and has been widened and deepened to suit the dimensions of the Dortmund and Ems Canal. Below the junction lock at Haneken Ferry, the locks in the canal and the canalised Ems have an available length of 165 metres (541⅓ feet), and entrance width of 10 metres (33 feet). The greater length and width of the locks, as compared with those of the locks in the higher reaches, were chosen on account of the different nature of the barge traffic between Dortmund and Gleesen, as

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* Zero is the zero of "Amsterdam Peil"; that is, Amsterdam standard level as fixed by royal decree in 1818.

compared with that between Gleesen and Emden. It has been assumed that the traffic from Emden up to Gleesen will be maintained by tugboats, each drawing two loaded barges, and that these will have to be passed through the locks together. From Gleesen to Dortmund and Herne, it is preferable, on account of the smaller cross-section of the canal as compared with the section of the open Ems, to tow one barge only, and to lock this craft alone through, leaving the tugboat behind in the lower reach when the traffic is sufficiently developed. In all probability electric towing will be introduced at no distant date, when tugboats will become unnecessary, at any rate on the short reaches.

There are four locks on the Haneken Canal, and five on the open Ems, between Meppen and Herbrum. This place is 214·3 kilometres (133½ miles) from Dortmund. Below Herbrum as far as Emden, no material improvements have been made in the Ems, as there was sufficient width and depth in the river to accommodate the canal-boat traffic. The open Ems is utilised for 45 kilometres (28 miles). The two entrance locks of the lateral canal, leading to the inland port of Emden, are 100 metres (328 feet) long. The water-level of the port of Emden is maintained at 1·14 metres (3¾ feet) above zero, and corresponds to the ordinary height of the tide at this port. The mean range of the tide at Emden is 2·70 metres (8 feet 10 inches).

The canal crosses the valleys of the Rhine and the Ems, the water-parting of which is situated on the high moors at Venne at 55 kilometres (34¼ miles) from Dortmund. Along this summit level the canal follows the right-hand crest of the hills of the valley of the River Emscher. It was found necessary to keep the canal at this uniform high-level as far as Henrichenburg, in order to be able to overcome the whole fall to the next lower reach *in cumulo* by a canal-lift. The original idea was to establish a series of locks following the fall of the valley of the Emscher, but the idea had to be abandoned, as it was found that there was not a sufficient supply of water available at the highest point for locking. The water of the Emscher could not be used for such a purpose, as it is too foul, being polluted by the sewage of Dortmund and by the water pumped into it from numerous mines.

The canal crosses the water-parting between the Emscher and Lippe valleys in a cutting 10 metres (33 feet) deep to canal bottom. Across the valley of the Lippe the canal is carried on embankment, with the towing-path 13·5 metres (44½ feet) above ground-level. The River Lippe is crossed on a substantial aqueduct, with three openings of 21 metres (69 feet) span each. Crossing the water-parting between the Lippe and Stever valleys necessitated making a cutting 12 metres (39½ feet) deep. The embankment across the valley of the Stever is of the same height. The River Stever is crossed by another substantial aqueduct, having also three openings, but only 12·5 metres (41 feet) span each. The Ems is crossed at 7 kilometres (4⅓ miles) below the lock at Münster, on a massive aqueduct of four openings of 12·60 metres (41⅓ feet) span each. The canal has to overcome the greatest difference in levels within the drainage area of the Ems, at a point near Riesenbeck, where it is carried in a cutting 12·5 metres (41 feet) deep, through the underlying limestone formation near the Teutoburg forest.

Beyond the lock at Bergeshoevede the country descends pretty rapidly towards the plain, so that the distance to the next lock is only 1·1 kilometre (0·7 mile), whereas it was possible to place the succeeding locks leading towards the Ems at intervals of 2·9, 5·4, 8·7, 7·8, and 3·5 kilometres (1·8, 3·4, 5·4, 4·8, and 2·2 miles). Short reaches between locks cannot be recommended. When there is a considerable amount of traffic through the locks, the great quantity of water used for locking, causes perceptible variations in the water level, which variations are further enhanced by the flowing and returning currents between locks, caused by the admission or drawing off of water. Indeed, in the case of a reach 5·4 kilometres (3·4 miles) long, the wave caused by locking produces at times as great a difference as 10 centimetres (4 inches) in the water-level. It thence follows that the headway from the water level to the soffit of a bridge crossing over the canal, has to be made at least 10 centimetres (4 inches) more than that required by the load gauge of the barges. In the case of the Dortmund and Ems Canal this headway has been fixed at 4 metres (13⅛ feet).

In the Haneken Canal there is a fall of 10·67 metres (35 feet), which is overcome by three locks. The water-level above the regulating gates on the Haneken Canal is kept down by a massive overfall weir with free flow. The regulating gate is generally kept open, and is only intended to shut out floods in the Ems that are higher than the water-level in the canal. The Ems between Meppen and Herbrum is divided into five reaches. In the upper four reaches the water is dammed up by needle-weirs. At Herbrum sluices were considered necessary, as under certain conditions the water below the sluices can rise higher than above the sluices. The five locks overcome a total fall of 10·25 metres (33⅝ feet). Including the canal-lift and the two end locks of the Oldersum and Emden Canal, there are altogether twenty locks. At the end of each reach only a single lock has been built, but the position of each lock of 67 metres (220 feet) available length has been arranged in such a manner that a second lock can be added hereafter in every case if required.

Dimensions of Canal.

The Dortmund and Ems Canal has a depth of 2·5 metres (8 feet 2½ inches) and a bottom-width of 18 metres (59 feet). These are the standard dimensions fixed for all Prussian canals to be built in the future. On curves, the bottom-width is enlarged on the convex side. The amount of this widening of the bottom is regulated in every case by the radius of the curve and the admissible maximum length of the barges, in accordance with the rules fixed at the International Congress for Inland Navigation held at Vienna in 1886. In accordance with these rules, the amount of the widening of the canal bottom is equal to twice the versed sine of the arc whose chord is equal to the length of the longest barge, which has been assumed at 67 metres (220 feet). The amounts by which the canal bottom is to be widened have been rounded off to the nearest half-metre, and are arranged for certain groups of radii of curvature. They are for a radius of—

2,000 metres	(100 chains)	=	0·5 m.	(1′ 8″)
1,000 ,,	(50 ,,)	=	1·0 m.	(3′ 3⅜″)
500 ,,	(25 ,,)	=	2·5 m.	(8′ 3″)
400 ,,	(20 ,,)	=	3·0 m.	(9′ 11″)

The sharpest curves on the canal have radii of 400 metres (20 chains). On the Ems, the bottom-width of which is 30 metres (98½ feet) throughout, curves of 350 metres (17½ chains) were admissible. The clear bottom-width of 18 metres (59 feet) has also been adopted for all structures with vertical walls along the canal, which entails a contraction of the wetted cross-section of the canal, and consequently interferes with the free flow of the water at every such structure. The area of the standard wetted cross-section is 59·2 square metres (637¼ square feet); and the area of the cross-section where it is contracted by structures with vertical walls is 45 square metres (484⅓ square feet). For the rest, in every case where standard slopes could not be arranged, as, for instance, at bridges crossing over the canal, a standard width of 22 metres (72 feet) has been adopted for a height of one metre (3 feet 3⅜ inches) above canal bottom.

Earthworks and Protection of Slopes.

The cross-section of the canal in cutting and embankment is shown in Fig. 3. The cross-section is somewhat altered where the slopes are protected by stone pitching or cement-concrete slabs. The slopes of the canal were protected everywhere by either of these means wherever the nature of the ground met with was such that it could not be left even temporarily without some protection. With regard to the extra depth of one metre (3 ft. 3⅜ in.) provided in the canal on embankments, it should be mentioned that the long slopes have shown signs of weakness, and, consequently, it has been decided to strengthen their toes on the canal side, by raising the canal bottom one metre, for a width of at least 3 metres (10 feet).

Various methods adopted for protecting the canal slopes are shown in Fig. 4. Originally it was not considered necessary to face the slopes throughout, but during construction it was gradually discovered that the material used for forming the slopes was almost everywhere of a sandy nature, and not compact enough to resist the wash produced by passing vessels. The shortest length of faced slopes, measured along the slope, is at present 2·90 metres (9½ feet) long, and requires about 1·16 cubic metres of stone per lineal metre (1·39 cubic yards per lineal yard) of slope. The deepest point or toe of the facing to the slopes is placed 0·60 metre (2 feet) below the ordinary water-level, which depth was fixed by experiment, as it was found that below that depth the action of the waves did no damage to the slopes. In several places on long stretches a novel method of protecting the slopes has been tried, with excellent results as compared with steeper inclinations, which consisted in covering directly the 3 to 1 sodded slopes with a layer of loose rubble. On future works this method may probably be used still more extensively. In other places, on long stretches, the slopes of the canal are faced with cement-concrete slabs, 1·10 to 1·20 metres (3 ft. 7 in. to 3 ft. 11 in.) long by 0·5 to 0·6 metre (20 to 24 inches) wide, the proportions being 1 part of cement to 2 parts of sand and from 3 to 5 parts of gravel. The joints are simply plugged with moss. The slabs are durable if they are carefully made, and properly bedded on broken stone or coarse gravel, whereby the danger of their being undermined by the wash is prevented. In special cases, where the clay puddle was placed immediately below the layer of soil, cement-concrete slabs were also laid on a slope of 3 to 1. These slabs were made in sizes of 1·8 by 0·6 metre (6 feet by 2 feet), and 8 centimetres (3¼ inches) thick, and were strengthened by five pieces of hoop iron, 25 by 2 millimetres (1 inch by $\frac{1}{12}$ inch), embedded in them. The purpose of the hoop iron was to render the slabs less liable to break, especially when they are being carried and handled, and has answered fairly well. More recently, broken slabs, 8 centimetres thick as before, and measuring 1·20 by 0·6 metre (4 feet by 2 feet), have been replaced by new ones only 5 centimetres (barely 2 inches) thick, which had round iron bars embedded in them, which are not more costly and are less liable to break. An experiment has also been tried of covering large surfaces with a thin layer of concrete, with embedded wire-netting, on the Monier principle; provisions were also made to hold down the concrete to the slopes, but the result was not satisfactory. Irregular cracks made their appearance, the concrete was undermined by the water, and broke in pieces.

Alterations in the original cross-section of the canal were also required for the protection of its slopes, as provision had to be made against leakage by the use of puddle in embankments. As it was of the utmost importance that the puddle should form an unbroken, continuous layer, which should nowhere be broken through by the facing or pitching of the canal slopes, all designs that did not strictly comply with this requirement had necessarily to be rejected. Puddle became necessary everywhere in embankments where the spoil used for forming the bank was not suitable for making a watertight embankment. It was equally necessary in cuttings wherever the material cut through was either porous or where its stratification was liable to allow water to leak out. In both these respects the Dortmund and Ems Canal was under unfavourable conditions. The long stretches of high embankments across the valleys of the Lippe and the Stever had to be formed of the marly material derived from the cuttings. In the lower strata the marl was so hard that it had to be quarried, almost like stone; but it soon crumbled to pieces on exposure to air and water. Only after lengthy consideration and careful experiments with the material on trial lengths was it finally decided to make use of this marl for forming embankments. Experiments proved the possibility of making use of it for such a purpose, but only on condition that the marl heaps were effectually protected against the disintegrating influence of air and water. It was, however, impossible to prevent the subsequent settlement of the banks, formed of coarse, hard lumps, in spite of the care with which the lumps were broken up and all interstices filled. Considerable trouble from this cause was experienced, especially where the high bank joined the approach walls of the canal-lift. The marl banks were at first wholly encased in a covering of clay, as shown in the cross-section of the embankment across the valleys of the Lippe and the Stever (Fig. 5); but this caused further trouble, as it was found that the soil covering the outer slopes would not adhere to the clay puddle underneath, and slipped down in large patches. It was, therefore, decided later on, during the progress of the works, to dispense with the clay covering on the outside slopes, and to spread the soil directly over the marl, which has proved successful.

In the canal-bed the clay puddle has been covered over with a layer of sand, in order to protect it against injury from passing vessels. The stone pitching of the canal slopes was laid on this layer of sand. At some places, where the covering of sand had not properly set, it happened that both the layer of sand and the stone pitching slipped down together on the slope of the clay puddle. Fine sand was met with in many places, and also required special care for forming it into embankments; but it gave less trouble than the marl. The material in this case was rammed and watered. A cross-section of an embankment made of sand across the valley of the Ems is shown in Fig. 6.

On side-lying ground, where the canal is partly on bank and partly in cutting, the clay puddle was omitted wherever it could be assumed that if any leakage took place the water would run off underground, without touching the toe of the embankment. The average slope of the water running off from the topmost layers was in this case assumed at 1 in 8. Experience, however, proved that in many instances this assumption was fallacious, and the administrative authorities of the canal were consequently compelled subsequently to perform a great deal of supplementary work, and to pay compensation, because not only had the loss of water by leakage in the canal to be made good by an increased supply, but complaints were also raised by adjoining owners for swamping their lands. When making up his estimates, the engineer ought never to stint the sum to be set apart for making the bed and banks of his canal thoroughly impervious. The material used for making the canal watertight was clay throughout, which was well rammed; and in case of thick layers and high slopes it was also well trodden down by horses. The specified thicknesses of the puddle along the canal were 70, 50, and 30 centimetres (27½, 19¾, and 12 inches). The thickness should be nowhere less than 30 centimetres (about one foot). By way of experiment, a thickness of 10 centimetres (4 inches) was tried, but did not prove successful.

Canal-Lift, Locks, Bridges, and other Structures.

It is not proposed to give in this Paper a minute description of the various structures along the Dortmund and Ems Canal, which, moreover, without detailed drawings, could hardly be intelligible. It must, therefore, suffice to allude briefly to some structures of a novel and peculiar character, for the construction of which the building of the canal offered an opportunity. Anyone who wishes for more detailed information on this subject is referred to a series of articles which are now (1901) appearing in the *Zeitschrift für Bauwesen* (published by Ernst & Korn, of Berlin).

Canal-Lift. — The most important structure along the canal is unquestionably the canal-lift near Henrichenburg, which serves to overcome an average fall of 14 metres (46 feet) between the Dortmund reach and the main reach, and can be used by 950-ton barges, 67 metres (220 feet) long by 8·2 metres (27 feet) beam, and 2 metres (6 feet 7 inches) draught. All canal-lifts that have hitherto been constructed are only able to accommodate vessels of much smaller dimensions. The oldest structure of this kind is the Anderton lift for raising barges up to 150 tons carrying capacity; the next one was Les Fontinettes lift for 300-ton vessels, and three more lifts are to operate on the Canal du Centre, one of which, namely, that at La Louvière, was completed several years ago for 360-ton vessels.

In order to accommodate the largest vessel trading on the canal, the troughs of the Henrichenburg lift had to be made of a length which only allowed of a method of construction in which each trough was carried on a single point of support, which design in its turn would have necessitated the adoption of hydraulic rams. Moreover, as a matter of course, two troughs would have had to be adopted, in order that the weight of the descending trough might be utilised for counterbalancing that of the ascending

CANAL-LIFT AT HENRICHENBURG.

trough. Each trough of the new lift was of necessity to have a clear length of 70 metres (230 feet). If only a single large ram had been adopted, there might have been some difficulty in constructing such a ram or a trough of sufficient strength. The adoption of several small rams, on the other hand, might have proved a source of constant trouble owing to a want of harmony in the working of the several rams. Another system of construction had, therefore, to be chosen, which may be described briefly as a floating lift with a single trough moving in parallel guides. The substructure consists of five contiguous wells, each 9·20 metres (30⅛ feet) in diameter, and 30 metres (98½ feet) deep. There was no difficulty in sinking these, because hard marl was found of great depth at this point, and with very few fissures. When sinking the wells, the portion already excavated was lined, working downwards, with cast-iron cylinders. Each ring was 1·50 metres (5 feet) high, and was composed of sixteen segments. At the bottom of each well a mass of concrete was deposited in the shape of a hollow spherical cup. The wells are connected with each other by pipes, and are kept constantly full of water up to their brims. In each well there is a floating hollow cylinder or buoy, 8·3 metres (27¼ feet) in diameter, and 10 metres (32⅝ feet) high. These five hollow cylinders exert together an upward pressure of about 3,100 tons, which is equivalent to the weight of the trough when full of water, plus the weight of the five vertical supports upon which it rests. The trough is suspended by vertical bands in a kind of cradle, which, in its turn, rests on the five lattice-work supports carried by the floating hollow cylinders. The whole construction, namely, hollow cylinders, vertical supports, and the tank filled with water, is in perfect equilibrium, so that if any extra water is admitted the trough begins to sink, or, if any water is abstracted, the trough begins to rise. In order to control the movement both up and down, also to start the lift at the proper moment, or to stop it at any level, and to check the momentum at the end of the stroke, there are four massive vertical spindles, which are turned by shafting which acts on all four spindles simultaneously, and makes them revolve at a uniform speed. The spindles work in four nuts, which are attached to the cradle carrying the trough. Both ends of the trough, and also the two fixed shore-ends of the canal, are fitted with watertight gates. In front of each gate of the upper and lower shore-end hangs a frame-like wedge-piece of the shape of the cross-section of the trough. The wedge-piece is faced on both sides with india-rubber rolls, and its position can be adjusted to suit the variable water-level in the canal. The ends of the trough are also rebated to fit the wedge-piece. As the trough rises or sinks into position ready for locking a barge, it squeezes the wedge-piece against the corresponding shore-end of the canal, and makes the joint watertight.

The raising of a barge from the lower to the upper reach is performed in the following manner:—As soon as the barge to be raised has been brought into its proper position, the gates at the corresponding shore-end and at the end of the trough are coupled together and raised by a capstan, worked by a rack and pinion, the weight of the gates being balanced by suitable counter-weights. The barge then enters the trough, and the gates are lowered again, and uncoupled. If required, the water in the trough is lowered to its proper level by letting off a portion. The trough rises, and is stopped opposite the gate of the upper reach ; the gates are then coupled together, and raised, and the barge enters the upper reach. The power for all these movements is supplied by two dynamos, driven by steam engines of 220 H.P. each. One dynamo is sufficient to do the work, the other being kept in reserve. The pressure amounts to 220 volts, and a current of 800 ampères is required for starting.

The cost of the lift and the whole installation was 2,600,000 marks (£130,000). The contractors for the work were Haniel & Lueg, of Duesseldorf-Grafenberg, and the Bridge-Construction Company, represented by J. C. Harkort, of Duisburg. The electric installation was carried out by the Deutsche Electricitäts Werke Garbe, Lahmeyer & Co., of Frankfort-on-the-Main. The idea of a floating lift guided by screw-motion was suggested by Herr Jebens, engineer, of Ratzeburg. The time occupied in raising one barge and lowering another averages 25 minutes. This time is counted from the moment when the first barge enters the trough, to the time when, the trough having delivered the first barge and finished the return journey with a second one travelling in the opposite direction, this barge has passed out, and the trough is ready for the reception of a third barge. The actual raising or lowering of the trough occupies 2½ minutes. The lift has hitherto worked without any hitch ; it even behaved extremely well on one occasion when, by accident, the trough ran dry during a downward journey, and the apparatus had to act under conditions under which it was never intended to work.

The objection that can be raised against the adoption of a lift is that it has too many different working parts, the failure of any one of which may interfere with the proper working of the whole. A lift constructed on the floating-trough principle should only be adopted where the conditions for it are favourable, and a good foundation can either be found, or can be prepared without any great trouble and expenditure. In conclusion, it should be mentioned that when the further extension of the Dortmund and Ems Canal is taken in hand, it is contemplated to construct a flight of locks by the side of the canal-lift.

Aqueducts.—The great aqueducts upon which the canal is carried across the Lippe, Stever, and Ems are constructed entirely of masonry, forming noble-looking structures, which are well worthy of being studied by the engineer in every detail. In future works of this kind, it will be highly advisable to make the wing walls as long as possible, in order to ensure a proper watertight bond between the earthwork of the embankment and the masonry of the abutments. Experience has also taught the lesson that where the abutments are backed with clay-puddle, the off-sets or steps at the back of the walls should not be made very wide, because when the clay-backing settles, wide off-sets or steps prevent an even settlement of the whole mass of clay behind the wall. The portion of the clay resting on the off-set is held up, and the puddle is apt to break up into horizontal layers which may cause leakage. The importance of making and maintaining a watertight bond between earthwork and masonry may be gathered from the foregoing remarks. In all structures along the Dortmund and Ems Canal, the masonry abutments are lined behind with a layer of clay puddle from 30 to 70 centimetres (12 to 27½ inches) thick, which joins the corresponding layer of puddle of the embankment. As for the rest, the structures are made watertight with sheet lead, 3 millimetres (0·12 inch) thick, the first cost of which was considerable, but which gave excellent results and could be thoroughly depended upon. All horizontal and vertical surfaces were coated with a layer of cement-mortar 2·5 centimetres (1 inch) thick. The horizontal faces were covered with a kind of asphalte brattice cloth, and the upright faces were coated with wood-cement. The lead is hung in sheets, measuring 5 by 2 metres (16½ by 6½ feet), against the vertical faces, and is protected on the side facing the water by a timber framework covered with boards. The horizontal sheets of lead were further covered with tarred brattice cloth, upon which sand was spread, and upon this the paving was laid. The sheets of lead overlap each other by 20 millimetres ($\frac{25}{32}$ inch) and were soldered together by the oxy-hydrogen blast. The contracting firm for this portion of the work was J. C. Eckelt, of Berlin. The cost of the sheet-lead covering, 3 millimetres (0·12 inch) thick, was 19 marks per square metre (15*s*. 10½*d*. per square yard). The total cost of the sheet-lead covering, including the pavement and protecting screen, was 74,500 marks (£3,725) for the aqueduct across the Lippe, and 79,000 marks (£3,950) for that across the River Ems.

Bridges.—There are 185 bridges across the canal; two of these are swing-bridges, and the others are fixed girder-bridges, giving a headway of 4 metres (13⅛ feet) above the highest navigable water-level. The girders are all of mild steel. The square span of the bridges was fixed at 31 metres (101¾ feet), in consequence of which the cross-section of the canal is contracted at the bridges. In addition to this, the deep slopes had to be protected with stone pitching for considerable lengths above and below bridge, and for the whole height, which entailed an expenditure amounting to as much as 8,000 marks (£400) for some of the bridges. In the long run, it was found preferable to increase the spans of the bridges sufficiently so as not to contract at all the cross-section of the canal. The two arrangements are shown in Figs. 7 and 8. The ordinary bridges, crossing the canal at right angles, were built to five different types of drawings, according to the different widths adopted for the roadways, and the different maximum loads they had to carry. The widths fixed for bridges carrying ordinary field roads were 4·5, 5·0, and 5·5 metres (14¾ feet, 16 feet 5 inches, and 18 feet), and for public road bridges, 7 and 8 metres (23 feet and 26¼ feet), including footpaths. The former class of bridges were built strong enough to carry a rolling load of 10 tons, the latter 20 tons and a load uniformly distributed all over the bridge of 400 kilograms per square metre (82 lbs. per square foot). The number of bridges built to type drawings is 112. In special cases, special drawings were prepared for the bridge, to suit the particular conditions of the locality. The largest bridge, carrying the Aschendorf-Rhede road across the Ems cutting, has a clear span of 66 metres (216½ feet).

Across the down canal heads of the locks at Meppen and Bollingerfähr, there are two lift-bridges. These are intended to carry light country-road traffic only. In order to be able to give the necessary standard headway of 4 metres (13⅛ feet) under them when the water in the lower reach is abnormally high, the superstructure of these two bridges can be raised off the abutments by steel ropes and capstans. This arrangement has answered well.

The canal is crossed in several places by railways, which are in all cases carried over the canal.

Locks.—Among these, two deserve particular notice; namely, those at Münster and Gleesen, each with a fall of 6·20 metres (20⅓ feet). Both locks have side ponds, in order to economise the water required for locking, and to keep this quantity down approximately in proportion to that required for working all the other locks, regardless of their higher falls. Each of these two locks has two pairs of side ponds built at different levels. In the case of the Münster lock the area of a pair of side ponds is one and a half times the area of the lock chamber, and the saving of water for locking amounts to 54½ per cent. Each pair of side ponds of the Gleesen lock have the same area as the lock chamber itself, and the saving in water amounts to 50 per cent. To save time, however, the flow of water from the side ponds is shut off when a difference of 15 centimetres (6 inches) is reached between the water-levels in the locks and side ponds; and the saving in water is consequently reduced to about 52 and 47 per cent. respectively during ordinary working. The pairs of side ponds are arranged symmetrically on either side of the centre line of the lock.

The filling and emptying of the locks is effected by culverts, one on either side, formed in the side walls of the lock, and each having a sectional area of 3·32 square metres (35¾ square feet). Each culvert is connected with the lock chamber by seven pipes, having an aggregate sectional area of 3·71 square metres (40 square feet). They are oval in section, and open out into the bottom of the lock chamber, and are fixed at regular intervals along the lock. Communication between the side pond and culvert is effected by cylindrical valves of 1·80 metres (6 feet) diameter. The connection between the culvert and the high-level or low-level reach can be shut off by sluice-gates working on rollers; the side ponds can be filled or emptied in five minutes. To do this, the gates, sluice-gates and cylindrical valves are worked by electric power. Electricity is generated by a turbine, which in the case of the Münster lock is driven by the water for locking, flowing from the upper to the lower reach. The dynamos are assisted by an accumulator. The gates are circular curves in plan; they are made of steel plates, strengthened by horizontal girders and upright framework. The junction between the gate and the hollow quoins and pointing sill is made watertight with strips of timber.

The power required to work the sluice-gates shutting off the water from the upper reach is 5·2 H.P., to open the low-level sluice-gates 3·4 H.P., and to shut them 7·2 H.P.; to open or shut the lock gates 6·7 H.P., and to work the cylindrical valves 4·3 H.P. The same arrangement of culverts with openings in the bottom of the lock chamber has also been adopted for the 67-metre (220-foot) locks, and the 165-metre (541⅓-foot) locks for barge-trains, which were built with vertical side walls to save water in locking. The long locks for barge-trains along the Ems, where the water used for locking has not to be restricted, have massive heads in masonry, with culverts formed in the walls, but their chambers have sloped sides, pitched with blocks of basalt. To ensure the safety of barges in lock chambers with sloping sides they are kept off the slopes by vertical piles, driven along the toe of the slopes and firmly braced together. Experience has already proved that this pile-work will require constant care, and will be very costly to maintain. The construction of the gates is the same in all the locks. The arrangement of the sluice-gates working on rollers is also the same everywhere, but wherever the fall is small both lock-gates and sluice-gates are worked by hand.

The average time required for passing a barge through a short lock is

16 minutes ; and, on the average, 30 minutes are required for passing a train of barges through one of the long locks, including in both cases the time taken for getting into and out of the lock.

Weirs and Sluices.—In the canalised Ems, the water is held up in four deep-water reaches by needle-weirs. The needles are pine spars, 9 centimetres (3½ inches) thick, and each of them is provided with the necessary hooks, by means of which it can be placed in position or removed independently of the other needles. This arrangement may be recommended, because the gradual rise of the water allows of ample time to remove the needles one by one.

At Herbrum there is a set of six sluices of 8·5 metres (28 feet) span each. These were necessary, owing to the necessity of making provision for shutting out the water in the lower reach, which occasionally rises higher than the water-level in the upper reach. The sluice-gates work on rows of rollers, in a manner similar to that adopted on the Manchester Ship Canal (Stoney sluices). But instead of being hung on wire ropes, the sluice-gates on the German canal are worked by a rack and pinion, by which the downward movement can be better controlled.

Stop-Gates.—For the purpose of dividing the canal into isolated reaches, stop-gates of an entirely novel construction have been adopted. It was considered necessary to introduce such gates because every embankment of any great height, leading through a valley, forms a constant source of danger ; and it was originally thought advisable to isolate such lengths on high embankments by placing self-acting stop-gates at every change from cutting to bank, so that at the moment of danger the gates should automatically confine the emptying of the canal to the reach intercepted between two gates. As, however, the greatest care was subsequently bestowed upon making these very lengths perfectly secure, regardless of any expenditure that might thereby be incurred, and as the method of construction proved entirely successful, there was no longer any necessity for stop-gates for the isolation of these lengths. Yet, to provide additional security, stop-gates were put in everywhere in conformity with the original scheme ; but it was no longer considered necessary to make them self-acting. The purpose for which the stop-gates on the Dortmund and Ems Canal were adopted, was to be able to isolate a canal-reach in the shortest possible time, with a small expenditure of motive power. When not in use, they were not to interfere in any way with the navigation. On future canal extensions, especially on reaches of great uninterrupted length, stop-gates will most probably be placed systematically at regular intervals, say about 10 kilometres (6¼ miles) apart. Besides their value in preventing serious accidents, and their ordinary use in dividing the canal into short reaches, when in case of repairs they make it possible to run off the water from such a short reach, stop-gates will also be found useful on very long and almost straight stretches of canal, because in such a case they can be used for breaking the swell produced by strong winds blowing along the canal. Under special conditions, during strong gales, there is a possibility of the level of the surface of the water being raised as much as a centimetre in a kilometre (⅝ inch in a mile). The consequences of this might be serious, and its occurrence should be avoided if possible. Another reason for dividing long stretches of canal into short lengths is for the better control of the water-level in individual reaches at the time of heavy downpours and floods, when any dangerous rise in the water level caused by natural drainage can be prevented by draining off the surplus water from the canal. At the site selected for a stop-gate, the canal was enclosed between two parallel vertical walls, leaving a passage 18 metres (59 feet) wide between them. This passage is closed by a curved steel gate, consisting of a single skin stiffened and strengthened by a suitable framework. When not in use, the gate is swung out of the water (round a *horizontal* axis) and stretches like a hood or shield across the passage formed by the two parallel walls and at a sufficient height above the water to give the necessary headway for barges passing underneath. It is moved by two arms resting on a pair of trunnions revolving in bearings bedded in the side walls. The arms are prolonged downwards, and oscillate in slits in the side walls and carry counterweights, which automatically change their positions while the gate is being swung round, and thus control its movement. When the gate is being opened or shut, the whole mass in motion is always in perfect equilibrium in every position the gate may assume. Various experiments were made with these gates, which gradually led to a more and more simple construction of the apparatus, until a form was finally arrived at of both gate and machinery for moving the same that perform in a satisfactory manner the work for which they were designed.

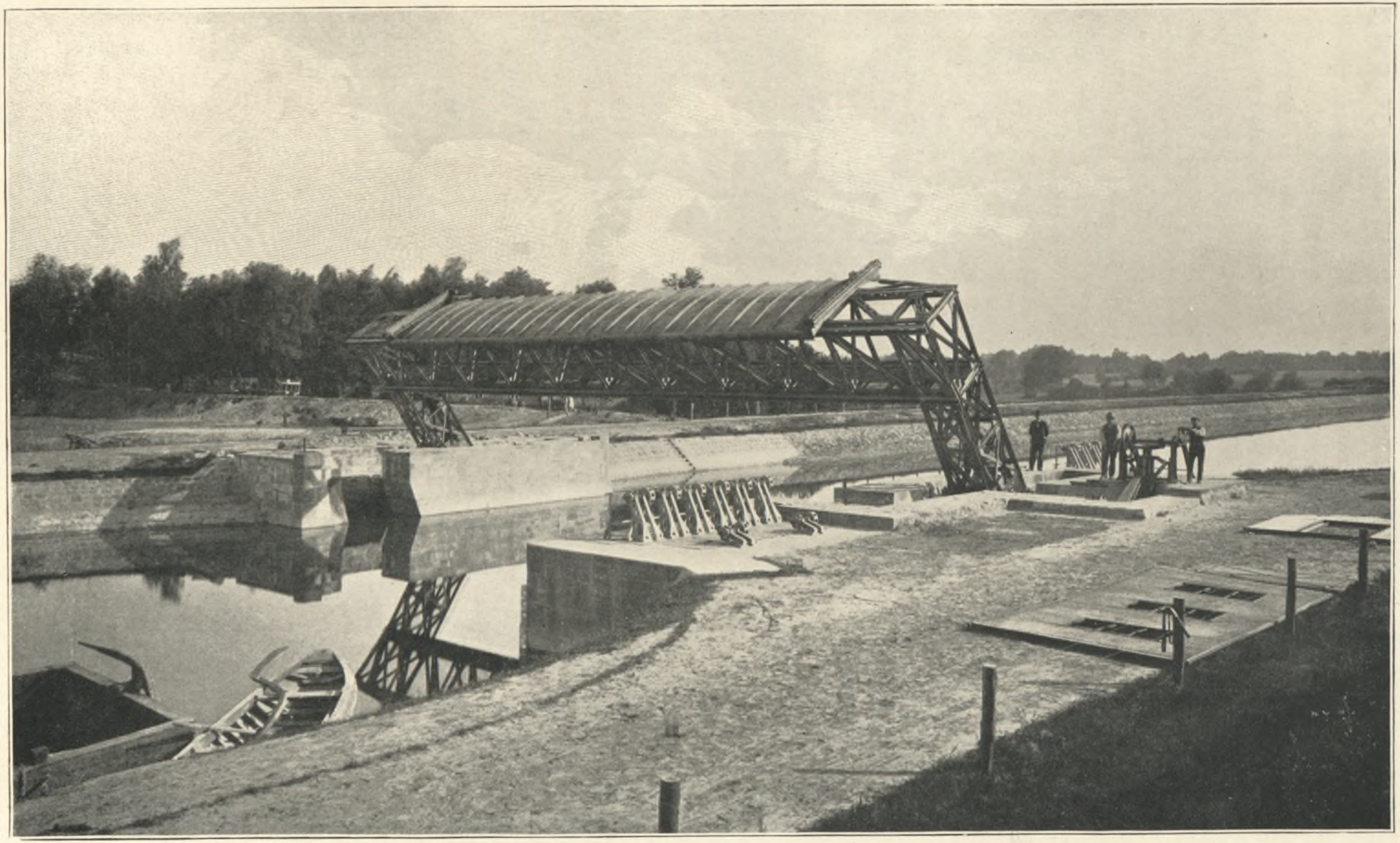
The stop-gates and the machinery for working them were made by the Gute Hoffnungshütte, of Sterkrade. Each stop-gate is closed by an attendant, who lives on the spot, and is bound to shut the gate immediately on receiving a warning signal, by the ringing of an electric bell, from the inspecting officer in charge of the adjoining canal-section. Culverts are provided in the side walls of each stop-gate, by means of which it is possible to adjust the level of the water in the two reaches separated by the gate.

Culverts and Syphons.—The watercourses crossing the canal, where it was not possible to divert them or lead their water into the canal, were carried under the canal, either with their bottom-levels unaltered wherever there was enough headway to do so, or otherwise in syphons. Up to 0·90 metre (3 feet) diameter the pipes under the canal are of cast iron, and beyond that size of riveted mild steel plates. The largest diameter was 1·34 metres (4 feet 5 inches). According to the quantity of water to be discharged, there were several pipes laid side by side, in one case as many as six pipes.

The larger sized brooks are carried through walled culverts. The largest of these culverts has a sectional area of 59 square metres (635 square feet), and carries the River Emscher under the canal. These walled culverts were carried out with the utmost care, both as regards materials and workmanship. The slightest neglect in this respect may lead to serious interruptions of traffic. When any slow-setting mortar is used for the masonry, no water is allowed to pass through the culvert on any account, not even temporarily during the construction of the works, if, as in the case of syphons, the water is likely to exert an upward pressure against the arched roof, unless there is a sufficient weight of earth and water above the arch to counteract the upward pressure.

Water Supply for the Canal.—In calculating the quantity of water required for feeding the canal, it was assumed that the loss of water through evaporation and percolation would amount to 8 litres per second for every kilometre of canal (2·83 gallons per second per mile). At the outset, after

STOP-GATE BEING RAISED.



the canal had been open for traffic, this loss was found to be 10·4 litres (3·68 gallons) or 1·56 cubic metres (343 gallons) for 150 kilometres (93½ miles) of canal in round figures. To this quantity had to be added the amount lost through locking at the end lock. The total amount thus required for replenishing the canal is supplied by a pumping station on the banks of the River Lippe, where the feed-water has to be raised to a height of 15·75 metres (51⅝ feet). At the present time there are three centrifugal pumps driven by steam-power, each pump being capable of raising 0·88 cubic metre (194 gallons) per second. Each pump is driven by a 400-H.P. engine. Although two pumps are sufficient to do the ordinary work, it is proposed to set up a fourth pump of the same size as the others, in order to have ample pumping power in reserve for all possible contingencies, in case there should be an extraordinary call upon the pumping power, as, for example, in case of having to refill long lengths of canal which, for some reason or other, had to be emptied. Besides the water supplied by the pumps, the canal is also fed by natural watercourses, which it has been possible to utilise for that purpose. Although the area naturally drained by these watercourses only amounts to about 60 square kilometres (23·17 square miles), which is comparatively small, the water derived from this supplementary source forms a valuable addition to the quantity which has to be pumped. It may be assumed that, on the average, for four months in the year the quantity supplied by these watercourses is sufficient to keep the canal replenished without pumping. During exceptionally wet seasons, especially, they are able to increase considerably the volume of water which can be stored in the canal to make up for any deficiency in the supply during the dry season. This can be done by raising the water-level 50 centimetres (19⅝ inches) in the two long reaches of 67 and 37 kilometres (41⅝ and 23 miles) respectively. The summit reach, the water-level of which is 70 metres (230 feet) above zero, is fed from the main reach by two pumps, each of which can raise 250 litres (55·3 gallons) per second. On an average, during the summer months, the water lost from the canal through evaporation and percolation amounts to a depth of 27 millimetres (1·063 inch) daily. As the greatest total loss by evaporation amounts to 22·3 centimetres (8¾ inches) during the month of August, that is 7·2 millimetres ($\frac{3}{10}$ inch) per day, this leaves about 20 millimetres (⅘ inch) per day for the amount lost by percolation per day, which quantity, it is expected, will diminish as the canal gets more and more watertight in the natural course.

Off-lets.—In order to drain off any surplus water that may find its way into the canal during extraordinary heavy rains, off-lets have been provided in suitable places, the positions of which have been fixed with due regard to the situations of the stop-gates. The off-let of the largest size on the Midland reach can discharge 13 cubic metres (2,861 gallons) per second from the canal into the River Ems. All the off-lets together can drain off 27 cubic metres (5,942 gallons) per second from the canal. The large off-let on the Midland reach, in conjunction with the two stop-gates provided there, proved very useful on the occasion of a breach of the bank in 1899. With their help it was found possible to lower quickly the water-level in the reach lying between the two stop-gates in question, having a length of 11 kilometres (7 miles), sufficiently to prevent any serious damage, as the flow from the breach could be stopped in a comparatively short time. It was found possible to do this without drawing off any water from the reaches lying beyond the stop-gates.

Canal Ports.—There are many ports along the canal for the interchange of traffic. There are large ports at the commencement of the canal at Dortmund, and at its termination at Emden. Dortmund has spent 5½ million marks (£275,000) on establishing a port suitable for every kind of traffic. The port is especially well equipped with the necessary appliances for loading coal on a large scale. Before the end of this year Emden will be connected with the sea by a well-lighted channel 10 metres (33 feet) deep at high water. To enable large sea-going vessels to load and unload, that cannot pass through the lock on account of their deep draught, extensive quays and wharves have been constructed outside the lock, with electric coal-tips, goods sheds and railway branch lines and sidings. In the inner harbour, with a depth of water of 6·5 metres (21⅓ feet), there are extensive quays and wharves which will accommodate industrial establishments of every description. Bonded warehouses also are to be constructed shortly in the outer harbour. Besides these two large ports a dock has been constructed at Münster 800 metres (2,625 feet) long by 60 metres (197 feet) average width. There is also a large port at the Herne terminus of the canal. The ports at Dortmund and Münster have been built with a Government subsidy, but are worked by the municipalities of the two towns. There are also ports at Leer and Papenburg for the accommodation of the sea-going trade. The other ports, especially the greater part of the smaller ports along the canal, are fiscal establishments. These ports, or rather wharves, are formed by widening out the canal on one side at the points in question by about 10 metres (33 feet) for one or more ship-lengths. To provide berthage for from four to eight ships, triangular-shaped basins have been hollowed out, in which ships can be swung round. Private owners also are permitted to establish such wharves or docks, with Government sanction, and no charge is made for loading or unloading cargoes at any of these private landing-places. At all public quays and wharves a charge of two, four or six pfennig (·24*d.*, ·48*d.* and ·72*d.*) per ton is levied on all cargoes, according to the three classes of tariff. No vessel is allowed to load or unload anywhere else along the canal except at a wharf or in port.

Cost.

The law authorising the construction of the canal sanctioned an expenditure of 64·68 million marks (£3,234,000) for the canal. By a supplementary grant this sum was subsequently raised to 79·43 millions (£3,971,500). The first grant was sanctioned in 1886, the work was begun in 1893, and on August 11th, 1899, the canal was opened by the Emperor.

The various items of expenditure were in round figures as under :—

Purchase of land	8·2	million	marks	=	£ 410,000
Earthworks and slopes	23·4	,,	,,	=	1,170,000
Maintenance during construction	1·3	,,	,,	=	65,000
Locks, bridges, etc.	22·8	,,	,,	=	1,140,000
Subsidiary works, ports, etc.	5·3	,,	,,	=	265,000
Reservoirs, pumps, etc.	1·1	,,	,,	=	55,000
Engineering, etc.	6·8	,,	,,	=	340,000
General expenses:					
Protecting slopes, clay puddling, and unforeseen contingencies	10·5	,,	,,	=	525,000
Total	79·4	,,	,,		£3,970,000

This sum is for a length of 252 kilometres (156$\frac{3}{5}$ miles). The expenditure was, consequently, about 316,000 marks per kilometre (£25,438 per mile).

Particulars of Cost.—One kilometre of artificial canal between Herne-Dortmund and Gleesen, 359,500 marks per kilometre (£28,940 per mile); one kilometre of river-canalisation between Meppen and Herbrum, 176,000 marks per kilometre (£14,168 per mile).

The following schedule of prices will also be of interest:—

	Marks.
Purchase of one hectare of land, including all incidental expenses	4,700 = £95 per acre.
One cubic metre of earthwork, including dressing and sodding and soiling slopes	0·94 = 8·62*d.* per cubic yard.
Clay-puddling bottom and sides of one kilometre of canal	65,000 = £5,232 per mile.
Protecting slopes per kilometre of canal	20,000 = £1,610 to 30,000 = £2415 per mile.

	Marks.	£.
Canal-lift at Henrichenburg	2·6 millions =	130,000
Each masonry lock of 67 metres (220 feet) available length	310,000 =	15,500
Each masonry lock of 165 metres (542 feet) available length	500,000 =	25,000
Each lock with masonry heads, but lock-chambers with sloped sides, 165 metres (542 feet) long	350,000 =	17,500
Each lock with side-ponds, with 6·2 metres (20$\frac{1}{3}$ feet) fall and electric working	670,000 =	33,500
Each needle-weir	170,000 =	8,500
Sluices at Herbrum	340,000 =	17,000
Aqueduct across River Lippe	650,000 =	32,500
,, ,, ,, Stever	434,000 =	21,700
,, ,, ,, Ems	900,000 =	45,000
Road diversion and crossing under canal at Olfen, width of road 8 metres (26$\frac{1}{4}$ feet)	110,000 =	5,500
One road-bridge across canal on steel girders—		
Width of road 4·5 metres (= 14$\frac{3}{4}$ feet)	25,000 =	1,250
,, ,, 5·5 metres (= 18 feet)	28,000 =	1,400
,, ,, 7·0 metres (= 23 feet)	40,000 =	2,000
,, ,, 8·0 metres (= 26$\frac{1}{4}$ feet)	42,000 =	2,100
Stop-gates, each	90,000 =	4,500
Pumping station on River Lippe	750,000 =	37,500
River Inspector's service yard	15,000 =	750

Administration.

The administration of the canal between Dortmund and Papenburg, including the branch to Herne, a total length of about 239 kilometres (148$\frac{1}{2}$ miles), is subject to the authority of the Chief Governor of Westphalia; that of the canal below Papenburg to the Government Chief in Aurich. The navigable portions of the Ems and the River Hase are also subject to the first-named authority. The portion under the Chief Governor of Westphalia is divided into two sections, each under a divisional Chief Inspector for River and Canal Works. The upper division, 149 kilometres (92$\frac{1}{2}$ miles) long, is divided into ten sub-divisions; the lower division, 89·5 kilometres (55$\frac{1}{2}$ miles) long, into five sub-divisions, each under a river inspector.

The annual cost of maintenance of the canal as far as Emden amounts to about 800,000 marks (£40,000), including the salaries of the engineering staff. The canal tolls are collected according to three different classes of tariff. The length along the Ems between Herbrum and Emden is toll-free. On the rest of the canal, between Herbrum and Dortmund, the following are to be the charges till April 1, 1905, for the whole length of 215 kilometres (133$\frac{1}{2}$ miles):—1st class goods, 50 pfennig, or 6*d.* per ton; 2nd class goods, 25 pfennig, or 3*d.* per ton; 3rd class goods, 10 pfennig, or 1⅓*d.* per ton. On and after April 1, 1905, the tolls to be levied per ton will be 70, 50 and 30 pfennig (8·4*d.*, 6*d.* and 3·6*d.*). For shorter distances the charges are reduced in proportion to the length traversed by the barges. The tolls are reckoned on the net cargo. Empty barges pay for one-tenth of their carrying capacity on the scale charged for 3rd class goods.

Mode of Working the Traffic.

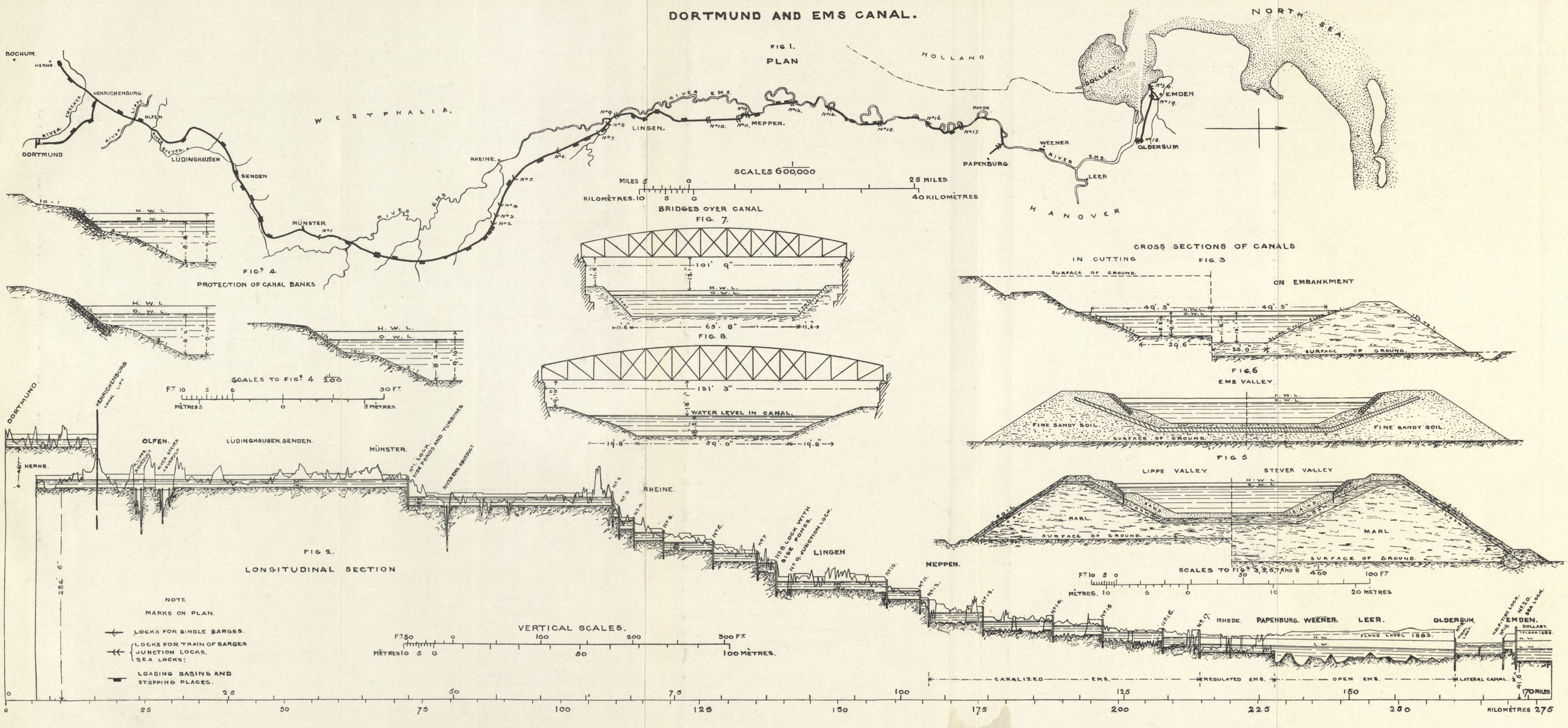
After mature consideration it was decided, in view of the uncertainty about the amount of traffic that might be expected, not to adopt at the outset any kind of central working of the canal traffic—for which purpose electric towage was contemplated—but to allow the barges to navigate freely and use steam tugs. Smaller craft can be towed by horses, a towing-path being provided for the purpose.

The cross-section of the canal allows of the passage of barges 67 metres (220 feet) long over all, with 8·20 metres (27 feet) beam, and drawing 2 metres (6 feet 7 inches) of water. Such a craft has a carrying capacity of about 950 tons. For the majority of new barges, specially built for working on the new canal, these maximum dimensions have been adopted. The barges were originally built with spoon-shaped prows and poops, but as some difficulty was experienced in steering barges fashioned in this way, straight posts were subsequently adopted, first aft, and later both fore and aft. The proportion of the area of the wetted cross-section of the largest make of barges to that of the canal is only 1 : 3·82. It will depend on the experience to be gained in working the traffic by towage, whether full use is to be made still further of the maximum permissible draught of 2 metres (6 feet 7 inches), or whether it will be more advantageous to reduce the draught by carrying less cargo. Most of the largest barges are towed by tugs, but some of the same tonnage carry their own engines. This latter kind of craft are specially intended for local traffic and for carrying better class goods. For transporting heavy masses the barge without her own engines will continue to be in demand. No difficulty has been experienced hitherto in towing a train of two and even three large barges with a single tug. Another variety of barges, specially built for service on the new canal, have only a length of 40 metres (132 feet) by 7·5 metres (24⅝ feet) beam, and 1·90 metres (6¼ feet) draught, with a carrying capacity of about 400 tons. For special purposes this kind of craft seems to be also well adapted.

For all cargo boats an average speed of 5 kilometres (3·1 miles) an hour is prescribed, but single steamers may on exceptional occasions travel at a greater speed by special permission of the canal authorities. In case of steamers, the bottom edge of the screw must be at least 0·75 metre (2½ feet) above the canal-bottom. This precaution has been taken in order to prevent any injury to the canal-bottom, which, on embankments with puddled clay bottoms, might have serious consequences.

The use which the sea-going lighters from the North Sea and the Baltic have made of the canal has been of special advantage to the development of its traffic. Very soon after the opening of the canal, a brisk over-sea trade was developed, especially with Bremen, and also with Hamburg, besides certain other Baltic ports as far as Danzig and Memel. The sea-going lighters using

DORTMUND AND EMS CANAL.



the canal are also of two special sizes. The larger ones have a length of about 60 metres (197 feet), 8 metres ($26\frac{1}{4}$ feet) beam, and are loaded for trips by sea till their draught amounts to 2·50 metres ($8\frac{1}{4}$ feet). After unloading part of their cargo to make them lighter and thus to reduce their draught to 2 metres (6 feet 7 inches), for the trip up the canal, they will still carry from 700 to 800 tons. The smaller lighters are 40 metres (131 feet) long, with 7 metres (23 feet) beam, and drawing 2 metres (6 feet 7 inches), and they carry about 400 tons. All these barges carry sailing tackle for emergencies; but, under ordinary conditions, they are exclusively towed on their trips across the seas. In favourable weather, a tug of 250 to 300 H.P. can tow two lighters. An average trip from Bremen to Münster occupies 8 or 9 days, and one from Hamburg to Münster from 10 to 14 days. The time spent on a voyage from the Baltic ports depends on the wind and weather.

Even Dutch and Belgian ports, especially Rotterdam and Antwerp, begin now to send traffic into the canal to Münster and Dortmund. The barges used for this purpose are the Dutch coasting and canal vessels called "tjalken." They travel along the Dutch canals, which are in communication with the Dortmund and Ems Canal at three points, namely, at Delfzyl, Haren, and Hanekenfaehr, *viâ* the Groningen Ship Canal, the Haren and Ruetenbrock Canal, and the Ems and Vechte Canal. The principal import goods carried on the canal are timber, corn, and ores. Of the latter, the Swedish ores from Lulea and Oxelsund occupy the foremost place. The principal export goods carried in mass are iron and coal. The traffic returns for 1900 show a total of about half a million tons, which figure will probably be doubled this year.

In conclusion, the Dortmund and Ems Canal is only the first portion of the proposed great canal-route between the Rhine and Elbe, and the full value of the new waterway will only be realised when the whole proposed network of canals is carried out. Until then its development will mainly depend upon the further development of the port of Emden, and the improvement of the route from Emden to the sea. Both these schemes are conceived in a bold spirit, and are being pushed forward with great energy, so that there is a fair prospect of their being completed this year and brought to a successful issue.

DISCUSSION.

M. DE TIMONOFF : Je ne sais jusqu'à quel point la question des nouveaux canaux projetés en Allemagne se rattache à celle qui vient d'être traitée. En Allemagne on se propose de créer un système général de canaux qui réuniraient tous les grands fleuves parcourant le pays. Je désirerais savoir si le Canal de Dortmund est construit de façon à faire partie de ce système d'ensemble.

M. HERMANN : Oui.

M. DE TIMONOFF : Il serait intéressant d'avoir aussi quelques renseignements sur l'avenir de ce système, de connaître le but qu'on poursuit et les principes techniques qu'on se propose de réaliser.

Mr. W. H. HUNTER : The canal so adequately described in this Paper reminds me of the River Weaver Navigation in the salt districts of Cheshire, with which I had the honour to be connected twenty years ago.

The bottom width is almost identical: we made the Weaver 60 feet wide, and this canal is 59·2 feet wide. The locks are 220 feet long; our locks were 225 feet. The depth is a little less, being 8·2 feet, whereas the Weaver was 10 feet deep with the lock sills put down for 15 feet; throughout there is a very striking similarity. Another somewhat curious similarity is found in the employment of the fall at the locks for driving turbines; that principle was carried out twenty-six or twenty-seven years ago on the Weaver with great success, and I have sometimes wondered—and I am glad to find it repeated here—why it has not been attempted in other navigations. The difference was that in those days—the pre-electric days—we used the fall at the lock for driving the turbine, which, through the intervention of friction gearing, easily moved the gates. In this case, the fall of the lock is used for generating an electric current, perhaps a more up-to-date method and in some ways a more convenient one. Again, I notice that the sluices for working the locks, as contrasted with the sluices for the discharge of flood waters, are cylindrical in shape; that is exactly the shape we adopted on the Weaver. I should like to ask the Author whether he has had any difficulty, as certainly we had, and still have, with these cylindrical sluices, owing to the fact that large masses of air are carried down through the centre of the sluice into the sluice way. A most unexpected difficulty occurred in that way, and led to something like a small hurricane, or a succession of hurricanes, in the conduits between the locks. Again, I notice the Author has been good enough to say specifically that he did us the honour of adopting the type of sluice-gate we have used largely on the Manchester Ship Canal; only he adds that instead of wire ropes such as those employed by us, working on balanced weights, he has adopted a rack and pinion, which he considers assists in putting the sluice-gates down. We have had no difficulty whatever in our method of getting the sluice-gates down; I do not know where the advantage is likely to come in, but I am glad to notice that "Stoney" sluices have been adopted there and that they appear to have given satisfaction. I am sorry that I have not had an opportunity of really studying the Paper, which is full of useful information of great value to those engaged in canal construction, and I am also sorry that I have so little knowledge of the route that I am not able to offer any remarks upon it. But we are all interested in the struggle which is going on in the German Empire at the present time with regard to canal communication, interesting for two reasons—first, because naturally it will affect us here in England, as it will bring German steel into this country, and will assist in the development of the German coalfields, and that may be a somewhat serious matter for us in the future; and secondly, because it is a method of development which seems to have fallen into abeyance in this country. People seem to have grown hopeless about canal communication; and if this German enterprise has the effect of stirring us up in this country, and of leading to the development of the canal system and the formation and improvement of canals on something like the lines laid down here, then it may be a blessing in disguise to us.

M. Mendes Guerreiro : Nous serions heureux de connaître les résultats de l'emploi du nouvel élévateur ; il n'était pas installé lors de l'Exposition Universelle de 1900, mais puisqu'aujourd'hui il fonctionne, il serait possible de nous renseigner à ce sujet.

Mr. Wilfrid Stokes : What has struck me most is the few remarks that have been made with reference to the sluices. It seems to me that the engineers of this project, although they have taken the Manchester Ship Canal sluices as their basis, have gone somewhat astray in their reproduction, because they referred to 5 H.P. or 7 H.P. as the force required to open and shut them. On the Ship Canal, there are sluices 26 feet deep and 30 feet opening which are controlled by one man.

Mr. W. H. Hunter : They are 27 feet 3 inches deep.

Mr. Wilfrid Stokes : If this sluice-gate can be controlled by one man, it seems that in reproducing them in Germany there must have been some error in construction or they would not require 7 H.P. to work them. They are, however, described as being on the "Stoney" principle. With regard to the rack, as contrasted with steel wire rope, my firm — Messrs. Ransomes & Rapier, Ltd.—have made many "Stoney" sluices, and we have used steel wire rope or sprocket chain; but there has been no difficulty in controlling the sluice-gates both in going up and going down, and it seems to me the introduction of a rack is a step in quite the wrong direction. There may, however, be circumstances which one does not gather from the Paper which make the rack more suitable than the wire rope.

M. Hermann : Je réponds d'abord à M. de Timonoff, qui désire savoir si on a appliqué à Dortmund les mêmes dimensions que celles qui seront appliquées au système général de canaux ; ces dimensions sont les mêmes. Le système du Canal de Dortmund est celui qui a été adopté pour l'avenir. La profondeur sera de 2½ mètres (8⅓ ft.), et la largeur de 18 mètres (59 ft.) ; les dimensions des écluses seront également les mêmes. Il y aura deux sortes d'écluses : une, permettant d'écluser un seul navire, et une écluse permettant d'écluser trois navires, avec remorqueur. Il n'y a des vannes cylindriques que pour les écluses d'épargne; pour les autres, on emploie des vannes à roulis. Pour la manœuvre des portes de l'ascenseur, on applique le système "Stoney"; mais il n'est adopté que pour cette partie-là, et évidemment avec contre-poids.

The CHAIRMAN : I think you will be unanimous in according a vote of thanks to the Author of this Paper for his contribution to our proceedings. Perhaps I may just make a few remarks on matters which have occurred to me.

First of all I am greatly struck with the enterprise of the German Government, who have spent something like four millions of money in perfecting this system of canal work. I am sorry to say that in this country we are not accustomed to such liberality on the part of Government, in making water-ways or other means of transport for the manufacturers of goods. Whether it is the right policy that these works should be executed by Government, or whether we should rely more on private enterprise, is a matter which is an open question, and on which very different opinions are held; but at the same time one cannot help recognising the great enterprise of the German Government who have spent this large sum of money. I should also like to point out that the cost per mile of this canal approaches £30,000, which is a convenient sum for people to have in their minds as the approximate cost of a canal which has not, as I gather, presented any very unusual difficulties, although great ingenuity is shown in the construction of the work. I cannot help thinking that the lift, if it occupies so long a time in raising and lowering, will be the cause of a serious block if the traffic is heavy; and one would like to have known a little as to how far the traffic that has been developed by the canal realises the expectations of those who designed it. The Author states that when the canal is extended, there will be a flight of locks by the side of the lift; apparently the engineers consider that they will not repeat the lift, but will return to the more old-fashioned flight of locks. Perhaps there may be good reasons for that, but at any rate it is very interesting. The gates appear to me to be a novel departure, and they seem ingenious and are reported as thoroughly efficient.

A subject extremely interesting to anybody who has to deal with water-works construction has been alluded to by the Author when he discussed the soakage of water through the canal on side-lying ground; you will see that it was estimated that a gradient of about 1 in 8 for the soakage of water through the ground would ensure the surface of the water keeping below the ground at the foot of the slope. I have had the matter brought before me on several occasions, and it is certainly one for which no royal road to knowledge can be found, depending as it does upon the nature of the soil and similar matters.

Lately I had to study a most interesting work in India : a large reservoir for the supply of a town, the reservoir being entirely made of sand, without any puddle or clay to retain the water. The gradient there, utilised through the sand, as far as I can recollect, was about 1 in 15 to 1 in 20. The gradient which the Author accepted was 1 in 8 through his embankment; but the gradient which I found in India, in entirely different soil, was much flatter. The engineer, having found that there was a slow soakage of water through the reservoir bank, adopted a perfectly proper expedient, which consisted in filling up the lower part of the bank with an additional embankment of earth, so as to ensure that the gradient was kept below the natural level of the ground. Unless that is attended to, not only is the water lost, but the work itself is in danger; and I am very glad indeed that the matter has been alluded to in this Paper, because it is a matter of principle which has to be studied in all cases by those who have to deal with water. There is one adage of universal application to those who have to deal with waterworks of every description, namely, that water is a foe which never sleeps, against which it is always necessary to take precautions; and immediately one sees even the approach of an attack, expedients must be adopted to counteract it, or the attack may develop into a serious disaster.

[Paper.]

NOVEL PLANT EMPLOYED IN TRANSPORTING THE EXCAVATIONS ON THE CHICAGO DRAINAGE CANAL WORKS.

By ISHAM RANDOLPH, Engineer-in-Chief.

HAVING had the honour of being asked by the secretary of Section II. for a Paper upon the methods of transporting material upon the Chicago Sanitary and Ship Canal Works, I interpret this to mean a description of the appliances used in excavating and removing the materials from that channel. Unless a work is of such magnitude and antiquity that its history has become a part of the universal stock of human knowledge, it seems proper to preface an account of the work itself with a brief statement of the causes which led to its being undertaken.

ORIGIN OF THE CANAL WORKS.

Chicago was an Indian trading post in 1812, and became an incorporated village in 1833. Its geographical location on the west shore of Lake Michigan, near its southern end, at the gateway to the great and then undeveloped West and North-West, gave it an importance which insured for it a phenomenal growth. With the building of the Illinois and Michigan Canal, completed in 1848, and the extension of railroads from the east, and their prolongation from the young city westward, population began to pour in, and business boomed ; marsh lands rose in price, if not in altitude ; and all the forces of a young and vigorous civilisation combined to build up an Inter-Oceanic Metropolis. Water for drinking purposes was drawn from the lake close in shore ; its unhealthiness caused a remedy to be sought ; and the first radical, and for many years effective relief, was afforded by building a tunnel (completed in 1866) two miles out into the lake, under the design and direction of the eminent engineer, E. S. Chesborough. However, with the growth of population, the supply became inadequate ; and the zone of pollution from sewage discharged into the lake often reached the intake to the tunnel. Other tunnels were built to intakes four miles from the shore, insuring an abundant supply, but not of unquestionable purity, for at frequent intervals even these distant ports of entry were invaded by sewage-tainted waters. During all this time the Chicago River, a stream with an outward flow, only discernable in times of flood, or when a falling lake-level drew off its waters, was an open sewer of ever-increasing foulness, a menace to health, and both unsightly and offensive. Relief accordingly had to be found, both radical and effective.

Descriptive Summary of the Design.

Passing over the history of the agitation and investigation of methods and expedients which led up to the work, though full of interest, we come to the legislation on the subject of this Paper. In 1889 a general law was enacted by the Legislature of Illinois, under which sanitary districts could be organised and boards constituted, whose powers permitted them to devise and adopt projects for the sanitation of their districts, levy taxes, and expend the income derived therefrom in the execution of the plans determined upon by them. Under this law, the first board of trustees of the sanitary district of Chicago was elected in November, 1889. The plan adopted by them, after careful consideration of all the alternatives which were worthy of being entertained, was the cutting of a channel across the divide which separated the watershed of the Chicago Basin from that of the Desplaines and Illinois Valleys, whose slope is toward the Mississippi River. The location adopted is but a restoration of conditions which geological research assures us once obtained before the Laurentian groove afforded an eastern outlet for the great lakes. The lowest point in this divide was only 11·72 feet above the datum plane of Chicago, which coincided with the low-water stage of Lake Michigan in 1847. The Chicago River has a north branch and a south branch, which separate from the main river about a mile inland from the lake. The south branch again forks about four miles south-west from its confluence with the main stream. This second bifurcation occurs near Ashland Avenue and Twenty-sixth Street in the city of Chicago. About three-quarters of a mile from this bifurcation the main channel of the sanitary district connects with the west fork of the south branch of the Chicago River at Robey Street. The channel, as now in use, is described under three divisions: the first division extends through a clay formation for 7·8 miles, and has a bottom width of 110 feet, with side slopes of two to one, giving, with the minimum depth of 22 feet, a width at the water-line of 198 feet. This section is to be widened by dredging, to afford the full flow of 600,000 cubic feet per minute, and the bridges are all built of a span to admit of this enlargement. The next division is through glacial drift for 5·3 miles; it is 202 feet wide at the bottom, has side slopes of two to one, and with the minimum depth of 22 feet has a width of 290 feet at the water-line. The gradient through these two divisions, 13·1 miles long, is 1 in 40,000. The next division, beginning at Willow Springs, is through rock, or rock overlaid with glacial drift; it is 160 feet wide at the bottom, and has vertical sides, with two off-sets of six inches each on each side, giving a resulting width of 162 feet at the water surface. The length of this division is 14·95 miles, about seven miles of which is thorough rock-cutting of an average depth of 36 feet. The gradient through this division is 1 in 20,000 feet. The total length of the main channel proper is 28·05 miles. It discharges into the Desplaines River at Lockport, and the outflow is controlled by regulating works, consisting of seven steel lifting-gates of the "Stoney" free-roller type, each 32 feet wide, and one bear-trap dam, 160 feet wide, having an oscillation of 17 feet. The volume of material excavated from this channel was 26,887,347 cubic yards of glacial drift, and 12,276,026 cubic yards of solid rock, making a total of 39,163,373 cubic yards; and 388,405 cubic yards of masonry were built in retaining walls.

Besides this work, which comes under the head of the main channel, the diversion of the Desplaines River involved the excavation of 1,801,339 cubic yards of glacial drift, and 258,659 cubic yards of solid rock. Enlarging the Desplaines River below the controlling works, involved the excavation of 558,172 cubic yards of glacial drift, and 571,871 cubic yards of solid rock; and 1,382,965 cubic yards of earth were dredged from the Chicago River, making a total of 43,736,379 cubic yards. The work, for convenience in designating the several contracts, was divided into sections, each approximately a mile in length (there were twenty-nine sections in 28·05 miles). These were numbered west from Willow Springs, in the rock sections, 1 to 15 inclusive, and lettered, in the earth sections, A to O inclusive (omitting J), from Willow Springs east. On this work there were seventeen contractors. The main channel is spanned by thirteen bridges, six of which are for highways and seven for railways. Of the last-named class, one carries eight tracks, one four tracks, and the remaining five two tracks each. They are all movable structures.

Cost of Canal Works.

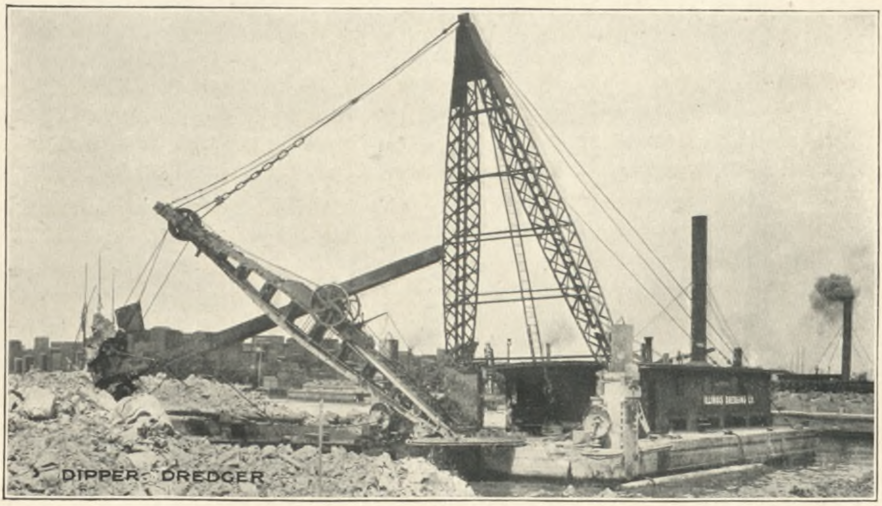
The cost of all this work, including 7,000 acres of land, interest account to January 1st, 1901, administration, and all other items was $35,182,846 (£7,329,633).

Dredgers Used on Canal Works.

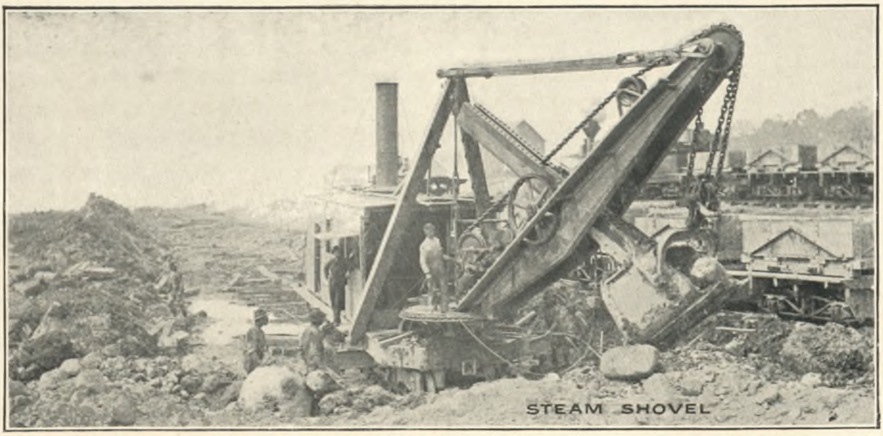
The dredgers used in excavating the Chicago River and section O (the first section west of the Chicago River) were of the ordinary dipper type; and unless the use of wire cable in substitution for chain cable on the cranes is worthy of mention, there was nothing novel about them. Some of them were machines of great power, with dippers whose capacity was six cubic yards. The excavated material was taken away in dump scows, some of which were built of steel, and towed out to an assigned dumping area in Lake Michigan.

With the exception of A, B, part of C, all of O, and part of 6, all of these sections were excavated by dry methods. On sections A and B there were two hydraulic dredgers used, one brought in at great cost through the old Illinois and Michigan Canal, the other built alongside the site of the work, at a cost of $40,000 (£8,333). These dredgers were constructed under the direction of Lindon W. Bates. The essentials of these dredgers were, first the hull, a flat-bottomed barge about 105 feet long and 33 feet wide. The equipment consisted of four horizontal boilers, 100 H.P. each; a 250-H.P. Westinghouse engine directly connected to a centrifugal pump 6 feet in diameter, with 20-inch suction and 18-inch discharge pipes. The suction pipe, where it left the barge, had a flexible joint to admit of its position being changed to meet the requirements of the work; and extending beyond the end of the suction pipe was a revolving cage with knives on it, so placed as to erode the material to be excavated. The suction pipe rested securely upon a wooden frame called a ladder, the upper end of which was hinged to the barge, and the lower end slung in chains rigged, for raising or lowering, to an overhanging boom or derrick projecting from the barge. On the top of

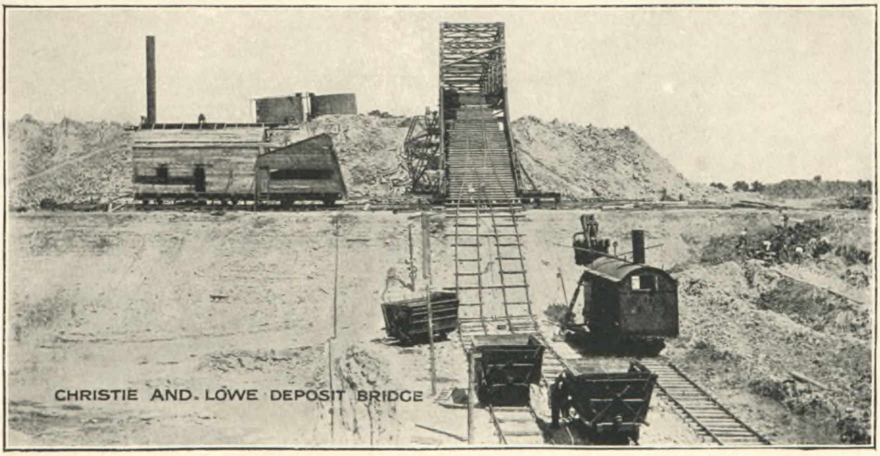
PLANT ON CHICAGO DRAINAGE CANAL WORKS.



DIPPER DREDGER



STEAM SHOVEL



CHRISTIE AND LOWE DEPOSIT BRIDGE

the suction pipe was a shaft, the revolution of which was actuated by an oscillating engine at its upper end, and cogging at the lower end, geared with cogging on the revolving cutter, and controlled its operation. At the opposite end of the barge from the mechanism just described was a spud which acted as a pivot. The dredger worked through the arc of a circle, the radius of which was the distance from this spud to the end of the suction pipe. The oscillation of the dredger from side to side, through the arc described, was effected by means of lines wound on a drum placed on the bow (or suction end) of the barge, the two ends made fast to the opposite sides of the channel; the revolution of the drum pulled the cable in one direction, and paid it out in the other, the direction of revolution being reversed as often as required to keep the suction pipe swaying from side to side. In operation, the pump was driven at about 250 revolutions per minute. The eroded material was drawn in with the water, and discharged through a series of pipes into the settling basins, which, in some instances, were a mile from the point at which the dredger was operating. This discharge pipe was of steel, made in lengths of about 20 feet, and the sections united by rubber tubing. A part of the discharge piping was carried on wooden floats; but several hundred feet of 18-inch pipe, with an outer jacket of thin steel, giving it a surrounding air-chamber, were used to secure flotation; and these had decided advantages over the wooden floats. The performances of these dredgers were exceedingly satisfactory; they excavated about 1,400,000 cubic yards of material from the canal. The best record of either dredger was 11,000 cubic yards in twenty-four hours. Besides the two described, two others were used. On section C the attempt was made to erode the material with water-jets. The erosion was successful enough, but the stuff was driven away from the pumps by this violent troubling of the waters, and the project was a failure there.

On Section 6, an inventive contractor, who had devised a very ingenious but unsuccessful excavator, "took heart of grace" and utilised his engine and boilers in an improvised hydraulic dredger, adding to the equipment already in hand a Heald and Cisco centrifugal pump of 12-inch suction; and with this aggregation of machinery mounted upon a scow, he produced, for about $10,000 (£2,083), a device which did very efficient work at a very small cost.

Excavations on Canal Works.

For removing top soils, ploughs and scrapers drawn by horses were used with advantage. The New Era grader was also brought into requisition by a few of the contractors. This machine is essentially a great breaking plough harnessed to a strongly-built wheeled frame. An endless apron is attached to one side of this frame, extending outward at an angle of about 40°, and so arranged with reference to the plough that the material turned by the mould-board falls on the apron, and is carried upward and outward to be discharged into dump wagons driven along the side. The apron is made to revolve by gearing which engages with cogs on one of the wheels which supports the main frame. This machine requires from twelve to sixteen horses to draw it and two men to operate it in addition to the drivers. In friable soils, it will excavate about 100 cubic yards per hour.

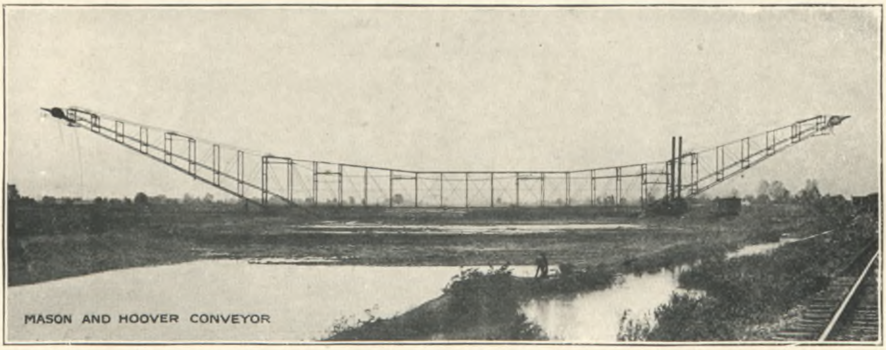
Steam shovels were the great reliance for excavating. Of these there were at one time fifty-two on the work, built by various manufacturers and varying but little in design. Those first in use proved too light for the general work coming under the all-embracing term, "glacial drift," which in our specifications was defined thus: "Glacial drift shall comprise the top soil, earth, muck, sand, gravel, clay, hard pan, boulders, fragmentary rock displaced from its original bed, and any other material that overlies the bed rock." The only other classification used was solid rock. Breakages were constant on the earlier shovels, and they were practically rebuilt, the parts as they broke being replaced with parts strongly reinforced. Boilers, too, had to be replaced by others of greater steam capacity. Even the latest and most powerful shovels had to be helped, by loosening up this tenacious material with explosives. With the exception of the Osgood shovels, whether built by the Marion Steam Shovel Co., the Vulcan Co. of Toledo, the Bucyrus Co., the Vulcan Co. of Chicago, or wherever built, the dipper handle was fitted with a cogged rack which engaged with a pinion. The Osgood shovel had no rack upon the dipper handle, but was equipped instead with a chain cable ingeniously rigged round a drum, the revolutions of which pushed the dipper down or released it, and at all times regulated the plane of its operations. The dipper was hoisted or lowered by two chain cables attached to the bale, and passing upwards and over two sheaves, one on each side of the apex of the crane, and thence down to the winding drums on the car, where the boilers and engines were located. This style of shovel is peculiarly adapted to the class of material encountered on the work, from its greater flexibility. The dipper seemed to wriggle its way underneath and between the boulders, much after the manner of the human fingers in grappling with materials into which the hand cannot be directly thrust. The shovels whose dippers were operated by rack and pinion, upon striking an obstacle they had not force to drive their way through, either broke or came to a dead stand, and had to be withdrawn and a more salient point of attack found for them. The steam shovel was the ally of nearly every device designed for removing the material after excavation, loading the material into cars, into wagons, on to belts, into cableway skips, etc.

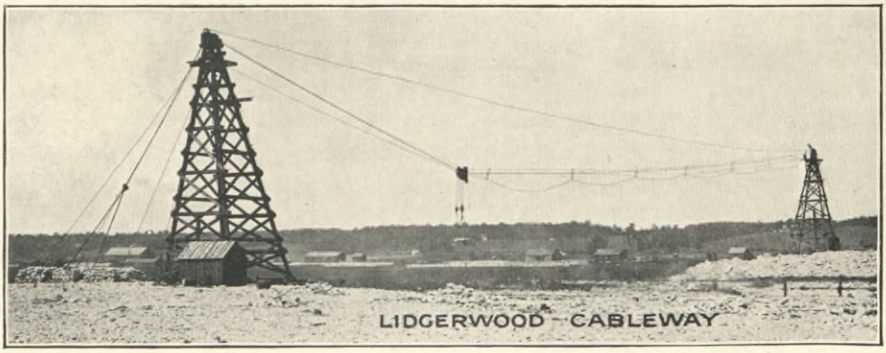
Conveyers for Removing Excavations.

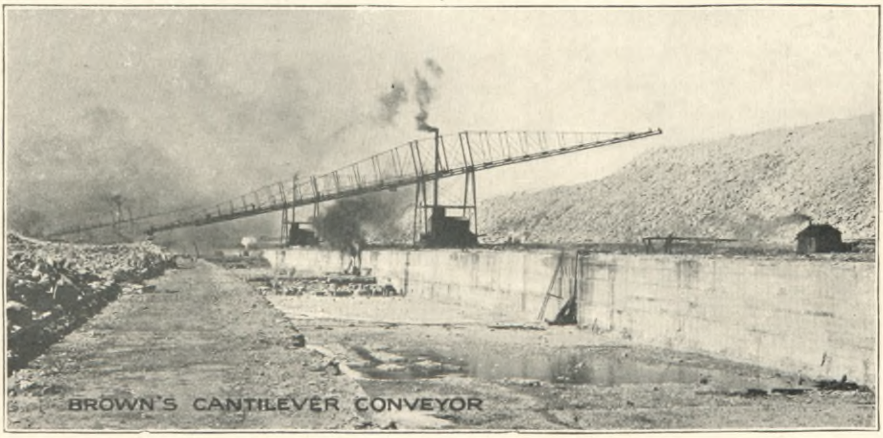
The Heidenreich Incline Conveyer was among the most successful devices used for delivering the excavated material on to the spoil area, which was brought into successful use by the contractors of that name, although the first of these devices which ever came to my knowledge was constructed by J. O. Wright, of the Western Dredging and Improvement Company, and used under very unfavourable conditions on the "river diversion" work. This device consists essentially of an incline, the frame of which, in elevation, is a triangle having two nearly equal sides, one of which forms the base, the other pointing upwards and projecting beyond the base; the third side forms the roadway which carries the tracks on which the cars are moved. There are two standard-gauge tracks on this incline, spaced ten feet between centres. The top section of each track, for a length of about ten feet, is pivoted like a teter-board, and becomes a tipple. The whole frame is mounted upon trucks, whose direction of travel is at right angles to the

PLANT ON CHICAGO DRAINAGE CANAL WORKS.


NEW ERA GRADER


MASON AND HOOVER CONVEYOR


LIDGERWOOD CABLEWAY


BROWN'S CANTILEVER CONVEYOR

longitudinal section of the incline; the platform of the base is extended sufficiently to carry engine, boilers, hoisting machinery, and dynamo for electric lighting. This device travels on tracks parallel with the channel; and a trestle extends from the foot of the incline down into the channel.

There are two cars used for alternate loading and dumping. A car is let down into the pit, and when loaded by a steam shovel, the signal is given to the engineer on the incline, who starts the hoisting machinery and hauls the loaded car up on to the tipple, where, as soon as its centre of gravity passes the axis of the tipple, it is thrown forward and its contents dumped. As soon as it is empty, the counter-weighting of the tipple causes it to right itself, and the empty car is returned to the pit. Meantime, the car on the other track has been loaded, and is being hauled up. The incline and its approach is moved forward by means of wire cables wound on a capstan, and so attached to the incline and approach as to ensure that all parts move simultaneously. There were nine of these devices in use upon the channel, showing an efficiency and economy which attests their fitness for the work. On the thorough earth sections their best record for any one month has been 968 cubic yards per shift of ten hours. As a further development of the inclines just described, Christie & Lowe terminated the incline so that the car would pass from it on to a bridge spanning the spoil area, the abutments of the bridge being mounted upon trucks travelling parallel with the channel. The double track of the incline became a loop track on the bridge, thus avoiding switches. The cars used are side-dumpers, and have a capacity of eight cubic yards. The hoisting apparatus is similar to that used with the inclines, but of greater power. The bridge is moved ahead as soon as the height of the spoil reaches nearly to the bottom chord. The bridge, with its approach, is moved along by a capstan and cable, and also the incline. The best month's average made by steam shovels working with these devices was 821 cubic yards per shift.

Mason & Hoover's Conveyer is essentially a bridge spanning the channel, with a cantilever arm extending out over the spoil area, the whole carried on trucks which travel on tracks on each side of the channel, laid parallel thereto. The bridge carries a steel belt made in 4-foot sections, like pans, interlocking and hinged with 2-inch axles carrying flanged wheels 12 inches in diameter. This steel belt works in a metal trough with rails on each side, on which the pan wheels travel, which fits the cross-section of the channel, and extends up to the apex of the cantilever. There are huge sprocket wheels, one at the end of each cantilever, constructed so that the 12-inch wheels at the 4-foot intervals will drop into recesses on the circumference of the sprockets. The entire length of this steel belt is 1,300 feet. The driving power is transmitted by manilla rope, and the engine is 14 by 17. A separate car carries two 150-H.P. boilers, which supply steam for running the conveyer, and also for propelling the plough which loads it. This plough is of great strength, double-ended, so that it may be drawn back and forth across the channel without turning, and cut a furrow each way. An ordinary hoisting engine operates this plough. The cable is made fast to each end of the long plough beam; and from the end next the hoisting machine, it is wound round the drum, and passed on across the channel through a pulley-block, and then made fast to the other end of the plough, so that direction of motion is governed by the direction in which the drum is revolved. The conveyer is driven at the rate of 120 feet per minute; the plough is started at the top of the cut, and the successive furrows are lower and lower, until the bottom is reached; and the material thrown from the ploughshare rolls down the side of the cut on to the conveyer. As the bottom is reached, the efficiency of the plough diminishes, until at last the bottom has to be cast on with shovels, which is a slow process. The conveyer advances about two feet at a time; its best recorded achievement for any month was 509 cubic yards per ten-hour shift.

Bates' conveyer consists of a car on which is mounted the 50-H.P. engine, boiler, and necessary gearing for driving the conveying belt. The car moves parallel with the channel, a frame extends down from the car into and across the channel excavation, carrying at short intervals concave rollers, on which a roller belt, 22 inches wide, travels. This belt passes under a hopper, in which a pair of cylinders set with great steel knives, which intermesh, revolve and break up the clay, which is dropped into the hopper by the steam shovel (60-H.P. Toledo). The granulator is driven by a 120-H.P. engine. The granulated material is delivered on the belt, and carried up over the power car, where it is delivered on another similar belt carried on a bridge which spans the spoil area. This is a very efficient apparatus and shows, for its best record, 920 cubic yards per shift as an average for one month.

Depositing Plant.

On some of the sections the steam shovels, loaded directly into cars which are run in trains, are hauled away to the dumping grounds by locomotives, of which there were thirty-two on the work. The Thatcher pneumatic dumps present the greatest novelty in dump cars. They are side dumpers, with the body pivoted on a longitudinal axis at the centre of its width. The dumping is effected by means of an air cylinder attached to the running gear, with the outer end of its piston rod attached to the under side of the car bed. When the train is made up, all these cylinders are connected continuously by hose with each other, and with the air-pump on the locomotive. The engineer operates the dumps by manipulating the air valves, in the same way that the air brakes are handled. On some of the sections the loaded cars are hauled up out of the cut on steep inclines by hoisting engines of great power, and when on the upper level are drawn by horses or locomotives to the spoil area.

Channelling Machines.

Throughout the rock sections the sides are cut down vertically by channelling machines, of which there were as many as eighty-two in use at one time on the work. These devices consist essentially of a vertical boiler mounted on four wheels, and carrying a vertical engine which supplies the power for propelling the machine by means of a worm gear, and at the same time operates the channeller, which is a great chisel with a "z"-shaped cutting-edge made fast by clamps to the lower end of the steam piston-rod. A section of track of proper gauge is so laid for this machine that the chisel will come directly on the line of the edge of the channel; and the machine moves back and forth, cutting its way until the limit of depth for the slope on which it is working is reached. Each machine will cut about 100 superficial feet per shift of ten hours. Taking a channel of the dimensions of the canal, the cost of channelling amounted to about 6 cents (3*d.*) per cubic yard, or about 17¾ cents (9*d.*) per square foot of surface channelled. We have had upon this work both the "Ingersoll & Sargent" and the "Sullivan" machines.

Drills.

On great works the ring of the churn drill and the merry click-click of the jumper has almost ceased to be heard; and instead, the ear is wearied with the din of emitted steam, and the quick, sharp impact of the drill as it chips its way down into the rock. The steam drill has wrought a mighty revolution in the cost and the celerity with which rock excavation can be effected. We had on the work about 193 drills, driven largely by compressed air. Ten of the rock sections were equipped with air compressors, from which power was taken all along the section to run the drills, pumps, etc. The contractors considered that the cost of a compressor plant on a work of this magnitude was money well invested; such an equipment cost about $12,000 (£2,500). Its convenience, and the ease with which the power can be distributed through pipes and hose, commend it to general approval.

Dynamite was the staple explosive on the works, and we used about 8,000 tons. The blasts were fired by electricity, so that all charges were exploded simultaneously. Overlying the solid rock on some of the sections, there was a great deal of glacial drift that could not be excavated by the steam shovels until it had been shaken up by explosives. For this class of blasting, holes were drifted in horizontally just above the rock line, twelve or fifteen feet back from the face of the cut; and the burrows or galleries thus formed were charged with dynamite, and exploded. This method of horizontal burrowing is called "coyoting."

Cableway.

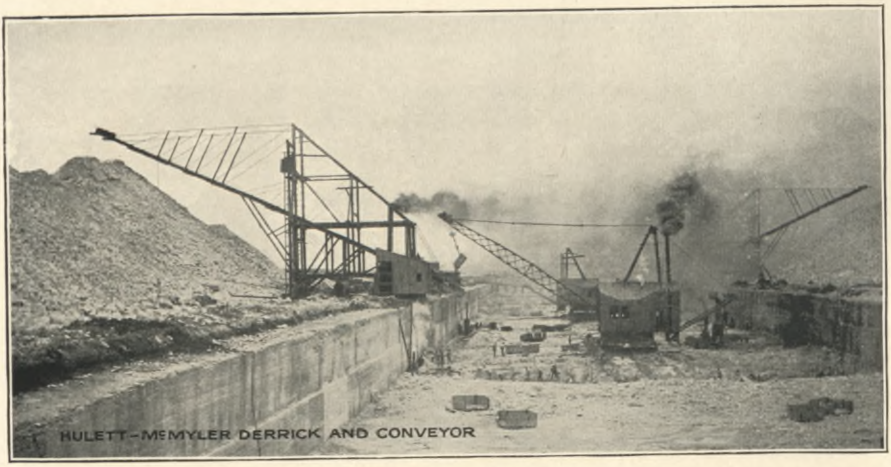
The Lidgerwood cableway proved a very efficient conveyer. The carrying cable is stretched across the channel from the tops of supporting towers. These towers are strongly built of wood, about 90 feet high, placed far enough apart (usually about 700 feet) to span the channel and the spoil area. Each tower is mounted upon a platform about 40 feet wide and 108 feet long, the towers being mounted on the ends of the platform nearest to the channel. They are firmly guyed to the corners on the outer end of the platform, which is heavily ballasted to resist the upsetting strain which comes upon the tower from the weight of the cable and its load. The towers are designated as head and tail towers; and under the head tower is the operating machinery. The platforms are mounted on sixteen pairs of standard-gauge car-wheels, whose travel is parallel to the channel, and at right angles to the cable. On one of the platforms was mounted the operating machinery, boilers, and hoisting engines; on the cable, a cage, or truck, was mounted, carried upon three grooved wheels which support it and travel on the cable. Immediately below these three sheaves, three more sheaves are carried by the cage, two of which are used for hoisting, and the third for dumping. The hoisting engines operate the three cable-drums with their respective cables; one of these connects with the head-tower end of the cage, is wound on the power drum, passed up again over a suitable sheave in the top of the head-tower, thence across to the tail tower, round sheaves properly located to prevent interference with the other cables, and thence back to the tail-tower end of the cage, completing the circuit and making an endless rope. This cable drags the cage back and forth. The hoisting cable and the dumping cable are wound on the same drum. The hoisting cable passes from its cage pulley through a sheave, which is attached to the lifting chains of the skip or hod ; this skip is a pan made of boiler-plate steel having a capacity of 90 cubic feet, or $1\frac{9}{10}$ cubic yards of rock *in situ* (estimating the increase in bulk as 80 per cent.). These three lifting chains are hooked to the two sides and back of the skip, and brought together and fastened to the lifting block ; and in the rear of the lifting block, and attached to it by a connecting bar, is a smaller sheave, round which the dumping rope plays. This pulley is made fast by a chain to the rear lifting chain of the skip. When the skip has been loaded, lifted out of the pit, and run out to the spoil-bank, the dumping cable which, as before stated, is wound on the same drum with the hoisting cable, and virtually travels at the same speed, is, by means of a lever, thrown on to a drum of greater diameter, which winds it up more rapidly than the lifting cable, and tips the skip forward, discharging its load. The empty skip is then returned to the pit, and a loaded one removed. This dumping apparatus was devised by H. C. Locker, of the firm of Mason, Hoge & Co.

The engineer operating one of these machines is directed entirely by electric-bell signals, in obedience to which he moves the cage back and forth, hoists or lowers the skip, and causes it to dump at the proper place. The life of the main cable is measured by the number of cubic yards it will take out before becoming unsafe, and is considered to be from 70,000 to 75,000 cubic yards. Large masses of rock are often lifted out, simply by attaching a chain to them and making them fast to the lifting apparatus. Stones containing three to four cubic yards are moved in this way. One stone weighing 16,800 pounds was safely landed on the spoil-bank. The best performance of any one of these machines of which we have any record was 615 cubic yards per day ; but this is far above the average performance, which may safely be taken as about 400 cubic yards per day. There were nineteen of these appliances on the work.

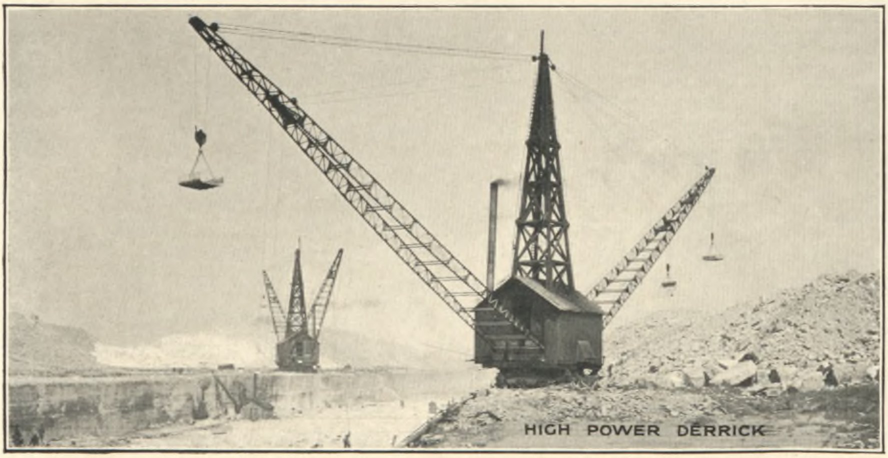
Brown's cantilever conveyer proved wonderfully efficient in handling blasted rock, and had the best record of any device on the work. It is essentially a platform, about 40 feet square, carried on four sets of trucks supporting the four corners. These trucks travel on two tracks solidly laid with heavy steel rails to a 3-foot gauge, parallel with the channel. The tracks are 39 feet centre to centre. The platform carries the engine, boilers, and machinery necessary for operation. A steel tower, composed of four corner posts properly braced and stayed, rises on the platform to a height of 53 feet on the channel side, and $60\frac{5}{8}$ feet on the spoil-bank side, and supports in equilibrium a bridge, 355 feet long, on an angle of 12° 50′ to the horizon, with the down grade toward the channel, across which it extends about 140 feet.

This bridge carries a track on which a trolly car runs. This trolly car is hauled up and down its length of travel by an endless cable wound on a

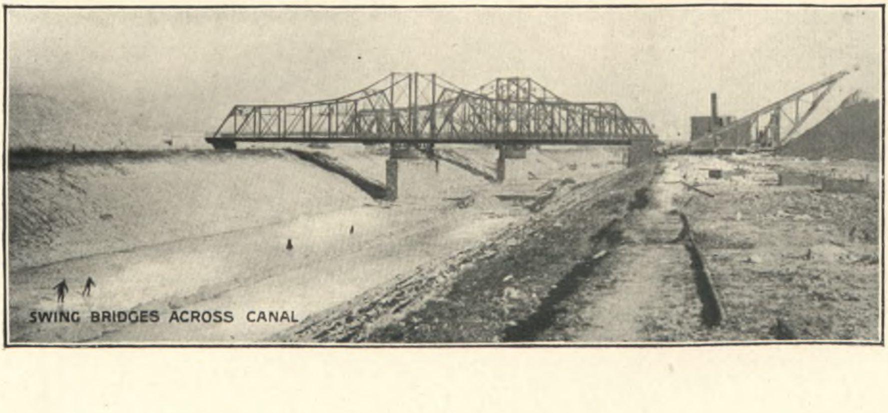
PLANT ON CHICAGO DRAINAGE CANAL WORKS.



HULETT-McMYLER DERRICK AND CONVEYOR



HIGH POWER DERRICK



SWING BRIDGES ACROSS CANAL

hoisting drum in the engine-house below; it carries a very ingenious construction of sheaves, triggers, etc., for raising and lowering the skips, and dumping them on the spoil-bank. The excavation is made across the channel, giving a working face corresponding with its width; nine skips are required for working; and from forty to forty-five men (muckers) are engaged in loading them. The skips or hods have a capacity of 75 cubic feet, or about 7,500 pounds of broken limestone. The time consumed in lifting a skip, running it off, dumping it on the spoil-bank, and returning it to the pit, is about fifty seconds. The best record of any one of these machines is 890 cubic yards in 10 hours 45 minutes; but this is considerably above the average day's work, which may be taken at 550 cubic yards. We had eleven of these devices on the work.

On two of the sections were devices known as the Hulett-McMyler high-power derrick and conveyer, an excellent derrick, self-poised, mounted on a turn-table like a swing bridge, and capable of hoisting very heavy loads. The scheme, as at first worked out, was that the high-power derrick should hoist the skip out of the pit, and discharge its load on to a car on an incline at right angles to the channel, but mounted on tracks which travelled parallel with the channel. The car on the incline was then hauled up to its high end and dumped. These devices did not achieve a success likely to lead to their use on future public works of this magnitude.

The high-power derricks used on Section 14 were very ponderous and powerful. They, too, are mounted on turn-tables like swing bridges, and are self-poised, instead of being counterweighted as the McMyler machine is: they have double booms which counterbalance each other. From the platform resting on the turn-table, a tower rose to a height of about 100 feet; within this tower, at its base, was housed the operating machinery for rotating, and for hoisting and lowering the skips. The mechanism is very powerful and ingenious. The booms were each about 160 feet long. They were worked in pairs, one on each side of the channel, because the booms would not reach across the excavation. They are moved along on rollers and blocking, just as houses are moved. Their performance did not fulfil the expectations of their projectors; and their best record was 372 cubic yards per shift of ten hours.

I have now described all of the main mechanical features presented on this work, many of them the outcome of its stupendous requirements. This work is bound to exercise a wonderful influence as an educator, and embolden men to undertake enterprises more vast than were considered practicable before its success had been demonstrated. The great array of mechanism brought into being for its construction, which earned vastly more than it cost to produce, was, most of it, without a sphere of usefulness after the work was completed, and, as a rule, became the prey of junk dealers, who dismantled it and sold the metal for what it would bring as raw material.

In conclusion, as a corollary to the work already done, we are engaged in giving the Chicago River, which is the main artery of supply for the sanitary and ship canal, dimensions commensurate with the new uses to which it is being put. The stream is being widened to 200 feet, with a channel depth of 26 feet. Centre-pier bridges are being removed, and their places supplied by modern structures of the bascule type.

DISCUSSION.

Mr. W. H. Hunter: Unfortunately, although these papers were sent to me a week ago, I have been travelling from place to place, and they only caught me up last night; I have therefore had no opportunity of looking at them.

I notice, however, that amongst the multitude of plant there are two dredgers built under the supervision or direction of Mr. Lindon Bates. These dredgers, working all through the twenty-four hours, raised on the average about 460 cubic yards an hour; one may consider 460 cubic yards as approximately equivalent to 700 tons an hour, working throughout the twenty-four hours. The point about it is that these dredgers were said to have cost 40,000 dollars each, or £8,333 English money. Now I should like to ask Mr. Brown how it is that he cannot build a dredger in this country that will raise 700 tons an hour working for 24 hours in a day, at a cost of something like £8,000 or £8,500? Generally the plant is suitable for a special class of work only, and one that very seldom obtains in this country, namely, the deposition of the soil on the banks of the canal, that is to say for excavation work carried out through practically waste lands; and of course there is very little of that kind of land in this country.

Mr. Andrew Brown: In this old country we are not quite up to such remarkable dealings with things as they are in America, but no doubt we try to follow them as well as we can. A great deal depends on the material that is lifted, the nature of the soil, and the power of the machines. You all know that water is easily lifted; and if there is a powerful pump supplied with plenty of water, you can lift a large quantity of sand. As a comparison with what has been done lately on the Clyde, I may mention that a bucket dredger lifted, not exactly sand, but clay at the rate of 2,000 tons an hour. At Durban, in South Africa, the suction dredgers "Octopus" and "Walrus" did good work in lowering the bar from 10 feet down to 20 feet depth of water in fifteen hours. They fill their own hoppers with 1,200 tons of sand in less than half an hour.

Mr. George Higgins: I would also like to make a remark about that portion of this Paper which refers to dredgers, and, more particularly, to that part which refers to suction dredgers. In the first place I might be allowed to find fault with this Paper, a fault which, I think, can be found with regard to many papers of the same kind, namely, that although information is given as to the quantity of material which is removed by a certain machine, yet none is given as to the nature of that material. I have often thought that in connection with excavation by dredgers we should have a scale of hardness or toughness, just as in mineralogy we have a scale of hardness varying from talc, which is soft, to the diamond, which is very hard.

The first dredger I constructed in Australia dealt with soft black clay, and the cost of delivering about half a mile away was a fraction of a penny per cubic yard. On the other hand, I have excavated with the same dredger, and delivered to a similar distance a material which may be described as marl overlaid with a bed of ironstone gravel, and the cost of that material was about half-a-crown. It is very difficult indeed to compare one excavating plant with another, unless we have some definite rule or scale of hardness or toughness. I think the time will come when we must adopt a regular scale in that way. With regard to the capacity generally of suction dredgers, I have not seen it explained in any work, although I have read many works on the subject, how it is that the capacity of suction dredgers increases so very rapidly with the increase in the diameter of the pipe. The first dredger I built in Australia had pipes of 20 inches in diameter; and when I saw how it worked I could not help wishing that opportunity might offer for the construction of a dredger with a 40-inch pipe. I have since then satisfied myself that for all practical purposes the capacity of the suction dredger will vary as the fourth power of the diameter of the pipe, that is, if the dredgers are in other respects properly proportioned.

I wish to demonstrate very briefly why it is that the capacity of suction dredgers increases so very rapidly with the diameter of the pipe. The way I look at the question is this: assuming a pipe of 20 inches in diameter, if we increase the diameter of that pipe to 40 inches, I think it can be shown we increase the capacity of the suction dredger sixteen times. In other words, the capacity of the suction dredger, other things being equal, should be as the fourth power of the diameter of the pipe. The water will flow towards the pipe necessarily in radial streams. If you take any section of one of those elemental streams, and if the larger pipe is 40 inches in diameter, the area of the larger pipe being four times the area of the smaller pipe, and the water flowing along the same stream-duct in each case, it is evident, assuming an equal velocity of flow through each pipe, that the velocity at any given point would be four times greater with the larger pipe than with the smaller, other things being equal. If the pipe is resting on the ground at the bottom of the river, and the water is flowing towards it, we know that the power which water has of transporting solid material in that way varies with the square of the velocity. Here, with the larger pipe, we have four times the original velocity; so we have this power of transporting solid stuff increased proportionately to the square of four, otherwise sixteen times the power is gained by the increased diameter.

Let us look at the matter in another way. We have, say, a long line of discharge pipe. At the very outset in Australia, the first dredger I had built involved delivery through a 20-inch pipe 4,000 feet long. It is rather a severe test to put a new dredger to. If we double the diameter of the discharge pipe, it is evident that the area is increased four times. We also assume a given velocity of flow. We arrange that the water travels along the discharge pipe at from 8 to 13 feet a second; and that will generally move clay which goes in lumps. If it is sand, we want a velocity of about 12 feet a second. We all know that the friction head lost in a pipe of larger diameter is very much less than the friction head lost in a pipe of smaller diameter. In what way can we take advantage of that? We can either allow the velocity in the pipes to be greater, or increase the density of the material. It is not necessary as a rule to increase the velocity in the pipe, but we can increase the density of the material; and we are able to do that when putting the suction pipe at the bottom of the river. Consequently, roughly speaking, we claim that the capacity of suction dredgers, if properly designed, increases as the square of the diameter of the pipe, and the engines, boilers, and all plant must be designed accordingly.

Mr. CHARLES H. WHITING : Mr. Bates will not be at this Congress, but as I was associated with him during the work on the canal, I should like to say in reply to Mr. Brown that probably, if his dredgers cost more than the price given in this Paper, they would be likely to be better built. The dredger on the Chicago Drainage Canal was built entirely of wood, and there was some second-hand machinery in it.

With reference to the classification of material, which has been referred to, I believe that Mr. Bates, and almost everyone who is favourable to his suction dredgers, would like to see some such scale adopted, because Mr. Bates' dredgers always suffer from a misapprehension of the material they work in. People say they can only handle very soft material, and they have to work under special conditions, and thus faint praise is given to them ; whereas, as a matter of fact, they are built to work in almost any kind of stuff, except rock. I received a letter from Mr. Bates recently in which he tells me that, on the Suez Canal, they made a cut of 151 metres (495 feet) long by 4·28 metres (14 feet) wide and from 1½ to 2 metres (5 to 6½ feet) in depth, in 29 minutes, which is a very creditable result when one considers that the material was very hard clay. The dredger in question was a new one, *en route* to Australia, which stopped in the Suez Canal and made a series of very successful experiments.

Mr. W. H. HUNTER : Was that dredger fitted with Mr. Bates' eroders ?

Mr. CHARLES H. WHITING : Yes, sir. I think Mr. Bates would be very glad if some scale were adopted.

The CHAIRMAN : Do you happen to know in what part of the Suez Canal the experiments were made ?

Mr. CHARLES H. WHITING : I believe at Kms. 84 and 132. They were made in ordinary sand and hard clay. So far as the work on the Chicago Drainage Canal is concerned, it is true that the material was soft ; it was turf and more or less ooze at the bottom of the river, but it was complicated by the presence of a great many boulders. We frequently would be swinging along and come upon a boulder as high as four feet ; and we would have to raise the cutter, pass over it, and drop the cutter on the other side. When the water was drawn off at the section, the configuration of the bottom in many places was such that you would hardly suppose that a suction dredger could have dealt with it. In other places, the bottoms were left as smooth as a newly ploughed field.

The CHAIRMAN : Can you tell us the cost of the plant on the Chicago Canal : the whole of the plant described in the Paper ?

Mr. CHARLES H. WHITING : It ran into many hundred thousand pounds.

Mr. W. H. HUNTER : What was the average cost per cubic yard of the work when that plant was charged to it ?

Mr. CHARLES H. WHITING : I have no knowledge on that point.

Mr. A. W. Robinson: I wish to confirm what the previous speakers have said about the cost of the dredgers referred to. I think if Mr. Hunter had seen them, he would think that 40,000 dollars would be a big price to give. The hull was simply a pontoon of wood, which would not have cost over 5,000 dollars; and, as has been said, some of the machinery was second-hand. Almost the whole of the machinery consisted of a pump, an engine and boilers. There was a rotary agitator which answered very well in dredging out the soft material, which was simply alluvial deposit on the surface, with a very difficult bottom underneath which had to be afterwards excavated by other means. The alluvial deposit would be about 10 to 16 feet in depth; and underneath lay big boulders and harder material which had afterwards to be taken out. It speaks very well for the contractors that, with so primitive and inexpensive a machine, they were able to get such good results.

Another fact in connection with this work I may mention is the method of letting the contracts. In that respect it was unlike most works in this country, where the contract is put in the hands of one responsible man, who organises his forces and lays his plans on a comprehensive scale. Here the work was divided amongst seventeen contractors, and they naturally adopted seventeen different ways of doing the work. It is only fair to say that while many of them were eminently successful, some were not successful; and they had to experiment and reconsider their plans, and in some cases the plans were even abandoned. But for that very reason this great work furnishes to engineers a most instructive object lesson of the various methods of accomplishing a given result. Those who are able to be on the ground and study the different methods which were in use, would come to the same conclusion I came to long ago—that there is more than one way of doing things. With regard to the capacity of the excavators, having been instrumental in furnishing some sixteen or eighteen of the machines used on that work, I may say we had to build some shovels there of great strength and power. The capacity of the shovels was not large for very difficult material, which in some places consisted of immense boulders in hard clay, and solid rock. It was found that the solid rock, in some respects, was a favourable material to work in; and it was taken out in a systematic way at a very small cost per cubic yard for rock. They knew exactly what they had to contend with in the rock, and there was no experimenting—it was simply channelling and blasting it out, and depositing it on the bank. But with the excavation which had to be done by steam shovels it was a different matter, and the output of the shovels varied very much indeed. The average size of the dipper of the shovels would be about 2¼ cubic yards, and some had a greater capacity. They would do from about 1,500 cubic yards per day of ordinary material to 2,000 cubic yards in soft earth, and from 800 to 1,000 cubic yards in very difficult material. I happen to have with me a photograph of one of the more recent shovels, similar to those used there, which has a record under favourable conditions of 45,000 cubic yards, or equivalent to about 60,000 tons, in nine working days. That was not done on the Chicago Canal, but it shows to what extent the development of that type of machine has been carried in America.

The CHAIRMAN: In proposing a vote of thanks to the Author of the Paper, I think we must all admit that the subject it deals with is one of much interest. It really touches the question of how far it is wise for those in charge of public works to go in expenditure on plant and machinery. For myself I cannot help thinking that it is an extremely urgent question in the older countries, where the conditions of labour are becoming very acute; and perhaps these conditions are still more acute in places like the United States, where labour is so highly remunerated. But the difficulty which engineers encounter in this country, at any rate, in having any idea when the work under their charge will be finished, is most often to be found in the conditions of the labour market and the supply of men when wanted. On the other hand, every contractor must also feel that there is a point beyond which he ought not to go in supplying plant to a work which he has to construct. I asked the gentleman from America who spoke just now whether he could tell us the whole of the expenditure on the plant of this work, and my reason for doing so was that a contractor in a very large way of business, to whom I was talking yesterday, told me that his estimate for plant on a large work was generally from about 8 to 10 per cent. of the total contract. This very large work of the Chicago Canal reaches a total of about seven millions of money; and therefore if my friend's estimate was at all near the mark, it would imply that from £550,000 to £700,000 could be judiciously spent upon plant on a work of that kind. Still it is a very difficult question, because an enormous amount of plant of that kind is a continual expense upon the work in question. If it is lying idle from any cause, it is eating its head off. There are many questions which any prudent contractor or engineer must take into his cognisance in estimating the proper amount of expenditure upon plant, and gauging how much should be done by machinery and how much by manual labour. That is a matter the answer to which must depend on different localities and on different circumstances.

With regard to the question of the dredger, I was struck with the price of the dredger to which Mr. Hunter drew attention; but I do not think it is at all a parallel case to any of the dredgers made on the Clyde, because it is evident from the context that it is what they call a dipper dredger, which is more like what we call a steam navvy. The capacity of the bucket was very great—no less than six cubic yards—but it could scarcely be called a dredger in the true sense of the word. It was evidently put together in a cheap manner, and I do not suppose it was worth much at the end of the work; so that I do not think Mr. Brown need be afraid of the comparison with the dredgers which he turns out, which, so far as I can bear witness, last many years and do their work at a cheap rate.

With regard to the amount that was dredged by the plant under consideration, the lift appears to have been low, and very different to the lifts we have to encounter in making approaches to ports where the ladder is often forty to fifty feet in the water. All these matters have to be taken into account in arriving at any comparison, and it only serves to show how difficult such comparisons are.

[Paper.]

IRRIGATION IN THE NILE VALLEY, AND ITS FUTURE.

By W. WILLCOCKS, C.M.G., M.Inst.C.E., Late Director-General of Reservoirs, Egypt.

As Horace compared the works of Pindar to the sustained flight of an eagle, and contrasted with them his own poems, which he compared to the cells of honey built up industriously by bees, so may the historical irrigation of the Nile Valley be contrasted with the patient labour of perennial irrigation. That basin irrigation, which has for upwards of 7,000 years held its course unimpeded and unchecked, may well take its place by the eagle's side during her most daring and sustained flight. The intricacies and lesser details of basin irrigation can be mastered by anyone who will make a methodical study of my book on "Egyptian Irrigation," and I shall therefore only give in this Paper the main features, and draw such lessons from them that others may be encouraged to learn the wisdom of the ancient Egyptians, and apply their knowledge to those new countries which have become the heritage of the European races, and whose permanent development can be secured by irrigation, and by irrigation alone.

Basin irrigation, as it has been practised in Egypt for thousands of years, is the most efficacious method of utilising existing means of irrigation which the world has witnessed. It can be started by the sparsest of populations. It will support in wealth a multitude of people. King Menes made his first dyke when the Egyptian nation was in its infancy. Egypt, in Roman times, supported a population twice as dense as that of to-day. The direct labour of cultivation is reduced to an absolute minimum.

Shakespeare's genius has crystallised the system for all time :—

> "They take the flow o' the Nile
> By certain scales in the Pyramid; they know,
> By the height, the lowness, or the mean, if dearth
> Or foizon follow: the higher Nilus swells,
> The more it promises: as it ebbs, the seedsman
> Upon the slime and ooze scatters his grain,
> And shortly comes to harvest."

How many undeveloped countries are there to-day whose rivers in flood run liquid gold which is never utilised? Taking my stand at Koshesha, on the earliest of the Egyptian dykes, I have often longed for the day when it might be my privilege to introduce into some new country this wonderful irrigation of ancient Egypt, and, like the engineer who gave undying fame to the name of Menes, give wealth and prosperity to some hitherto poor and barren land. How many thousands of modern pilgrims visit this strangely interesting land of Egypt, and go back to their homes with fragments of mummies, old pottery, and useless antiquities, and yet never carry away with them the secret by which that most ancient country renews its youth each recurring year.

If we cast back our view to the dawn of Egyptian history, we can picture the Nile Valley as consisting of arid plains, sand dunes, and marshy jungles, with reclaimed enclosures on all the highest lands. Every eight or ten years the valley was swept by a mighty inundation. We may well imagine with what awe the ancient Egyptians contemplated laying their hands on the great river, and saying to it, "Thus far and no farther." The seeds of future success lay in the resolve of King Menes' engineers to confine their attention to one bank of the river alone. It was the left bank of the river which history tells us was first reclaimed. A longitudinal dyke was run parallel to the stream, and cross dykes tied it to the Lybian hills. Into these basins or compartments the turbid waters of the flood were led by natural water-courses and artificial canals; and meantime the whole of the right bank and the trough of the river itself were allowed to be swept by the floods. It must have been on this wild eastern bank that were conducted all the hippopotamus hunts which are crowded on the wall pictures of buildings of the early dynasties. In all probability, the first six dynasties contented themselves with developing the left bank of the Nile. As, however, the population increased, and with it the demand for new lands, it became necessary to reclaim the right bank of the river as well. The task now was doubly difficult, as the river had to be confined to its own trough. This masterful feat was performed by the great Pharaohs of the XIIth Dynasty, the Amenemhats and the Usartsens, who, under the name of Sesostris, usurped the place of Menes in the imagination of the ancient world. They were too well advised to content themselves with repeating on the right bank what Menes had done on the left. By suddenly confining the river they would have exposed the low-lying towns of Memphis and Lower Egypt to disastrous inundations. To obviate this, they widened and deepened the natural channel which led to the Fayoum depression in the Lybian hills, and converted it into a powerful escape to carry off the excess waters of high floods; and so successful were they in their undertakings that the conversion of the Fayoum depression into Lake Mœris was long considered by the ancient world as one of its greatest wonders. They led the flood into the depression when it was dangerously high, and provided for its return to the river when the inundation had come to an end. By this means, they insured the lake against being at a high level during a period of flood. The gigantic dykes of entry and exit were only cut in times of emergency, and were reconstructed again at an expense of labour which even an Egyptian Pharaoh considered excessive. To understand how capable Lake Mœris was to control the floods, and turn a dangerous into a beneficial inundation, I should recommend a study of Major Brown's "Fayoum and Lake Mœris." As years rolled on the Nile widened and deepened its own trough, to which it was now confined; and, eventually, the time came when Lake Mœris could be dispensed with without danger. It was gradually reclaimed and converted into a province.

It was owing to this early development of the left bank of the Nile that all the ancient dynasties had their capitals on that side of the river; and it was possibly the rapid increase of wealth in the hands of the bolder people, who first settled on the right bank, which gave the later government of the country into the hands of the Theban nobles. This is only conjecture; but, in the hands of true Egyptologists, it may be of use in the study of those old-world events.

Basin irrigation holds the flood waters for some 45 days per annum over the whole of the valley. The water is in places 10 feet deep, and in others only one foot deep, while the average depth is about 4 feet. Now the retention of this water over the land for a period of six weeks permits of the thorough saturation of the subsoil in places where the subsoil is of proper consistency; and this water can be drawn on, in winter and summer, for maturing certain crops and growing others. It was where the subsoil gave a plentiful supply of water, and permitted of intense cultivation throughout the year, that we find all the ancient capitals of Egypt. Abydos has the finest subsoil water in the Nile Valley; Memphis has an excellent supply; while Thebes has the only good subsoil water on the whole of the right bank. Good subsoil water was to the ancient Egyptian world what the presence of a rich gold mine is to one of our new colonies.

Subsoil water supplies the link between basin and perennial irrigation. It explains the reason why modern Egypt is not satisfied with the irrigation which has come down from the remotest antiquity, but is desirous of conferring on the length and breadth of the Nile Valley those advantages which gave Abydos, Memphis, and Thebes their pre-eminence in the past. The thoroughly developed Nile Valley, with its permanent wealth and resources, may well betake itself to the more costly and remunerative methods of perennial irrigation; but for poor undeveloped countries to leave the rich mines of wealth which the flood waters of their rivers are capable of supplying, and to be turning their eyes to the unattainable irrigation from reservoirs and perennial sources, is as unprofitable as was Naaman's longing for the clear streams of Abana and Pharpar, while the turbid waters of the Jordan in flood were alone available. Any country which possesses rivers and streams whose waters are in flood for six weeks per annum, can betake itself to basin irrigation with more or less profit. The science of dams, weirs, and regulators has received such development during recent years that there can be no problem so difficult that it cannot be solved by experience and originality. Basin irrigation, and basin irrigation alone, allows of the thorough development of countries whose streams have short and turbid floods; whether it be the stately irrigation of the Nile Valley, perfected by the science and experience of 7,000 years; or the less perfect, but still highly developed and river-fed tank systems of Madras; or the primitive, but effective basins of Bundelkund, where the impounded water irrigates the crops on the down-stream sides of the basins for one season, and then allows of the basins themselves being dried and cultivated in the next.

The Nile in high flood rises 33 feet above its bed, in a mean flood 30 feet and in a poor flood 23 feet. The beds of the main basin canals are about 15 feet, and the cultivated land at the river's edge about 30 feet above the river-bed. The basins have an average area of 7,000 acres. Where the valley is narrow, they average 2,000 acres each, and where it is wide 20,000 acres; while some of the tail basins are 40,000 acres in extent. Each canal has about seven or eight basins depending on it, of which the last is always the largest. There are masonry regulators at the canal heads, at each crossing of the cross banks, and at the tail escapes into the river. In the more perfect basins the canals and escapes syphon under one another and overlap and supply each other's deficiencies, so as to meet the requirements of every kind of flood which Egypt can experience. Colonel Ross's work on the basin irrigation of Egypt, from which I have largely quoted in my book, is a monument of patient observation and a storehouse of information. Some of the canals are veritable rivers, discharging 15,000 cubic feet per second; but a good average canal discharges 1,000 cubic feet per second. The largest canal has a width of 250 feet, while the average width is 30 feet. Good basin canals discharge in an average year one cubic foot per second per 20 acres. Forty-five days suffice for a perfect irrigation. The cost of providing basin irrigation in Egypt for basins of 10,000 acres may be taken at £3 per acre thus made up:—Banks, £1 10*s.*; canals, 15*s.*; masonry works, 10*s.*; and bank protection, 5*s.* If the basins are under 5,000 acres, the cost will be nearly double this. The annual cost of maintenance is 2*s.* per acre; while the lands themselves are rented at £3 per acre. In well irrigated basins no manures are needed, and alternate crops of cereals and legumins have been reaped for centuries without the land having been exhausted in any way whatever. Where the subsoil water is good and double cropping resorted to, there manures have to be applied.

The foundation-stone of the conversion of the whole of Egypt from basin to perennial irrigation was laid by Mehemet Ali in 1833, when he began the construction of the barrages across the Nile branches north of Cairo. These weirs were intended to raise the summer level of the Nile 9 feet. As the ordinary summer level of the Nile was 5 feet above its bed, the weirs were expected to raise it 14 feet above the Nile bed. The old basin canals had to be considerably deepened to take in the summer supplies; while in other parts new perennial canals were dug. Perennial irrigation requires canals capable of discharging 1 cubic foot per second per 100 acres, as against 20 acres for basin irrigation. Some of the perennial canals are very capacious. The two largest discharge 20,000 and 15,000 cubic feet per second respectively. There are no artificial canals in the world like them. All the canals are liberally provided with regulators and locks; but escapes are, as a rule, lamentably deficient. This deficiency of escapes causes silt deposits on an enormous scale, and is a serious blot on the irrigation system of the country. However, it is impossible to find the funds for taking up everything at once; and the energies of the Irrigation Department during the last ten years have been chiefly directed to the provision of sufficient drains to meet that over-saturation of the soil, which all but the best regulated perennial irrigation invariably entails. After many years' experience in India and Egypt, I am convinced that the construction of drains and escapes should precede, and not follow the canals. It seems fatuous for engineers to be always over-saturating and half-ruining tens of thousands of acres of low-lying lands, during the improvement of hundreds of thousands of acres of high-lying lands, when it would be perfectly easy, with a little foresight, to secure all the advantages without piling up disadvantages. The drains have generally one-third the capacity of the canals. Dry crops require 1 cubic foot per second per 100 acres; and rice requires the same per 66 acres. The drains in drycropped lands provide 1 cubic foot per 300 acres, and in rice lands 1 cubic foot per second per 200 acres. Surface drains are made wide rather than deep, as deep drains encourage weeds.

The Nile in flood is a very muddy river, and teaches its lessons with a relentless hand. To avoid silt deposits as much as possible, all canal-heads are encouraged to take their flood waters from the top films, and not from the bottom ones, which carry most of the heavy silt. Canal-heads which are placed below reaches of the river where the banks are being cut away and scoured, silt up much more readily than those canals which start from well-regulated and protected reaches. The sites of new canals are very carefully chosen in this respect. Wide, shallow canals and watercourses silt less than deep and narrow ones. Great economies are made in silt clearances by those engineers who so grade their canals that the fall per mile of the first mile is greater than that of the second, and of the second than that of the third, and so on, until at the fifth or sixth mile the general slope of the canal is reached. The waters of the Nile flood, with a mean velocity of 2¼ feet per second for mean depths of 12 feet, give only slight deposits on canals which start from well-selected reaches of the river. These deposits, moreover, can be generally swept away by the comparatively clear supplies which follow the turbid floods.

Masonry regulators are given a depth of floor equal to half the head of water to be held up ; though in the Nile a depth of 10 feet is generally adopted, and in the main canals 7 feet. The ancient and modern Egyptians used vertical needles for regulation. The Egyptians were extraordinarily skilful in handling the largest timbers. Needles of 30 feet in length, and 9 inches by 6 inches, were commonly employed in 25 feet depth of water. Nearly all these verticals have been displaced by horizontal sleepers, and iron gates. Colonel Western and Mr. Reid introduced iron gates ; and they are gradually supplanting the other systems. I prefer the vertical needles, and should use them wherever possible, except at canal-heads.

Though all dry clearances are done by hand, at rates varying from 2*d.* to 3*d.* per cubic yard, all the wet clearances are performed by dredgers, at a general rate of about 6*d.* per cubic yard. In the larger canals, bucket dredgers are employed by preference. In the ordinary canals, centrifugal sand- or mud-pump dredgers are preferred. A long shoot deposits the material dredged into slurry pits, dug annually in the berms of the canals. If the soil is hard and stiff, grab dredgers are employed, though this form of dredger entails excessive wear and tear.

It would be a healthy innovation indeed, if the provision of suitable manures were to be considered as an essential part of a project for providing perennial irrigation. The day is not far distant, I believe, when governments which provide irrigation works will also provide manures, and sell the water and the manures together, one being as essential as the other ; I know well, from observation, that a well-manured field needs only half the water that a poorly manured field does ; and in years of drought and scarcity manures almost take the place of irrigation. Why should there not be a manure-rate as well as a water-rate ? Here in Egypt, the numerous ruins of old-world cities have hitherto provided manure for a great part of the perennially irrigated lands ; but these are being fast worked out, and other sources must be sought for. Farm-yard manure will never suffice for the intense cultivation in this country. In connection with this subject, I can recommend the study of a remarkably able paper on "Nile Cultivation and Nitrates," read by Mr. J. B. Fuller, C.I.E., before the Agricultural Society of England, and embodied in the 3rd Series, Vol. VII., Part 4, 1896. Egypt possesses, in the vicinity of Luxor, natural beds of nitrates of unlimited extent, which come down to the river's edge. These nitrate beds have been used from time immemorial, but were brought to the notice of the general public by Mr. Fuller. They contain only about 3 per cent. of pure nitrates, but as they are on the edge of the Nile, in a perfectly cloudless and very dry country, it might be possible, with the aid of the plentiful supply of water always at hand, and powerful lenses to concentrate the sun's rays and so hurry up the evaporation, to profitably work the nitrates. The demand for nitrates is without limit in the Nile Valley, as Nile water, though rich in everything else, is exceedingly poor in nitrates. Here is an enterprise which the Government should take upon itself, just as it takes upon itself the construction of reservoirs; but it will never be done until Egypt possesses an Under-Secretary of Agriculture of energy and real ability.

The perennial canals and collateral works have cost £4 10*s.* per acre, and the maintenance charges are 2*s.* per acre. The perennially irrigated lands are let at £5 per acre per annum.

I have purposely left the question of weirs till now, as it is connected with both basin and perennial irrigation. If it is possible, with skill and alignment, to lead the ordinary floods of a river into the basins, as it is generally possible on the Nile, no weirs are needed for basin irrigation. But even in Egypt the more thoughtful engineers, like Mr. Webb, are thinking of weirs for securing the perfect irrigation of the basins to the south of Abydos. Now the raising of the summer level of a river by 10 or 12 feet is being performed every day in many countries; but the raising of the flood levels of big rivers by even 3 feet is not easy to accomplish. The same permanent obstruction in a river which will raise its summer level by 12 feet will barely suffice to raise a high flood by one foot. In Egypt we have two completed weirs capable of raising the summer level of the Nile, and we have two in existence and two under construction for raising the flood levels of the river. I shall speak later on of the type of dam or weir under construction at Assuân, which is capable of great development as a regulator of floods on the mightiest streams, and which, if suited to its purpose here, may one day be imitated on South African and Australian rivers.

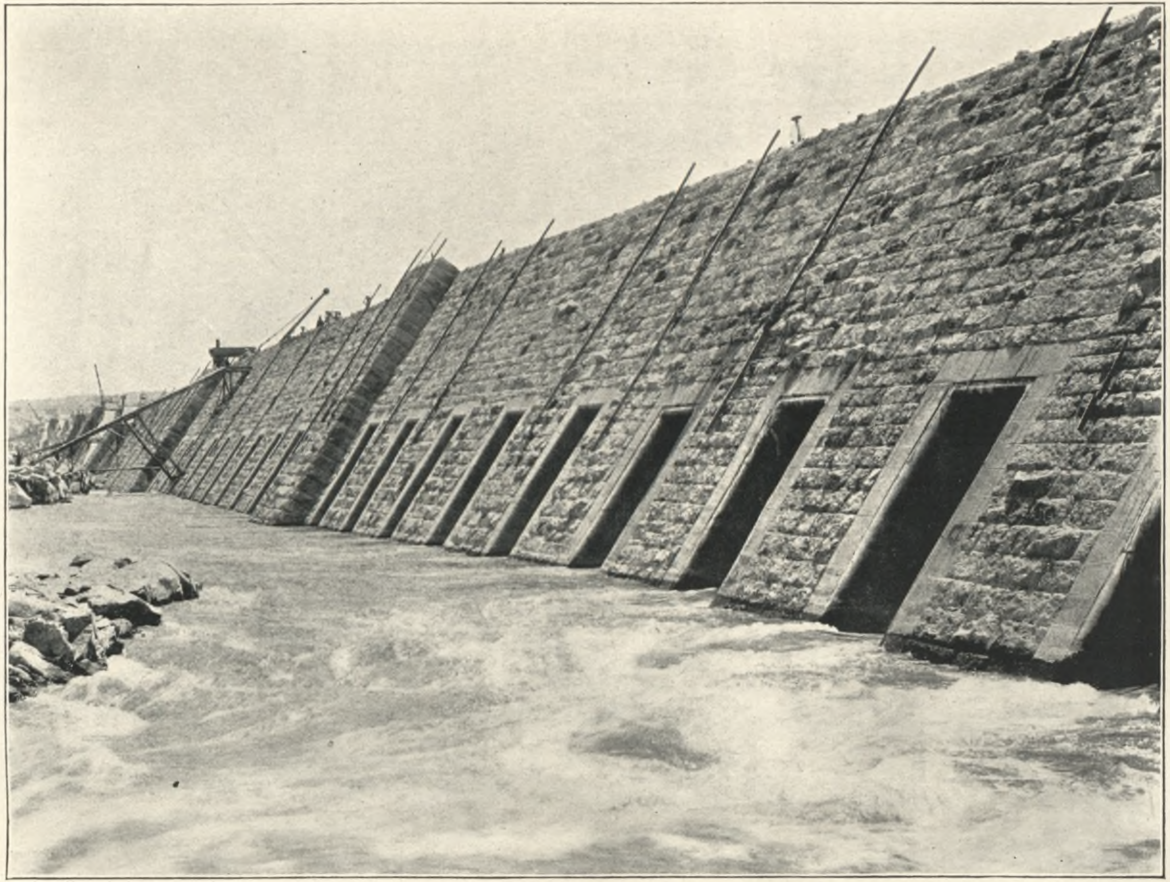
When Sir Proby Cautley and Sir Arthur Cotton were planning and executing the gigantic irrigation works on the Ganges and the Kistna in Northern and Southern India, whose signal successes gave irrigation an impetus which nothing can now arrest; Egypt, too, under the guiding hand of Linant Pasha and Mongel Bey, was being gifted with works of great magnitude on the Nile. While, however, the Indian works were decided successes from their inception, the Egyptian weirs or barrages were at the beginning a conspicuous failure. Time, however, has more than justified the execution of the Nile barrages. When the partial failures first pronounced themselves, the Egyptian Government needed one quality which it signally lacked—namely, courage to face the situation. Time went on and reports multiplied, as they always do in the hands of feeble men whose one idea of duty is the shirking of it, but no action was taken. Fortunately for Egypt, the British occupation of the country was followed by the advent of Sir Colin Scott-Moncrieff as Under-Secretary of Public Works. He was soon joined by the men who had learned their profession under him in India, and who counted it a high honour to work under his direction in Egypt. Though the element we were dealing with was water, we literally set the country ablaze. We made some mistakes and we secured many triumphs; but we went on conquering and to conquer. "Peace hath her victories no less renowned than war." Our chief possessed courage, that quality without which genius is cold, and opportunity never at hand. One of our successes was the barrage. The barrages across the heads of the Rosetta and Damietta branches of the Nile are regulators rather than weirs. The floors are flush with the river-bed, and consist of platforms of masonry 150 feet wide and 11 feet thick, with up-stream aprons and down-stream pitching. The platforms support regulating bridges, with 16 feet openings and piers 6½ feet wide. The roadway is 42 feet above floor-level. The Rosetta Barrage has sixty-one openings and the Damietta Barrage has seventy-one. The Rosetta Barrage has twenty openings too few, and the Damietta has twenty openings too many—but that is Egypt. Age cannot wither her, nor custom stale her infinite variety. The regulation is performed by three iron gates in each opening, raised and lowered by powerful travelling winches. The total height to which the water can be raised is 18 feet, but of this height nine feet are held up by the original barrages just described, and the remaining nine feet by subsidiary weirs recently constructed down-stream of the old works. The original barrages were designed and built by Mongel Bey. They long lay in neglect, but were tested and worked between 1884 and 1886, while they were under my charge. With Mr. Arnold Perry as resident engineer, the works were sufficiently repaired to hold up 10 feet of water, and the Government was encouraged to undertake their complete renewal under the direction of Colonel Western and Mr. Reid. Subsequent additions were made by Mr. Foster and Major Brown, and finally Major Brown designed and built the two subsidiary weirs, of which mention has already been made. The new weirs, constructed by Mr. Octavius Brooke as resident engineer, consist of solid cores of cement masonry 23 feet deep and 10 feet wide. On either side is a mass of clay 33 feet wide and 6 feet thick, overlaid by rubble stone 8 feet thick, and 50 feet wide up-stream and 150 feet wide down-stream of the solid cores. Very possibly the surface pitching, which is of Cairo limestone, will have to be replaced by basalt blocks from the quarries to the N.E. of Cairo. Major Brown is just bringing out a second edition of his "History of the Barrages," to which reference should be made for everything connected with the works.

I have already stated that the barrages are regulating bridges rather than weirs. They have been taken as types of the two new works of a similar kind under construction at Assiout, and at Zifta on the Damietta Branch. Both these works have masonry platforms, 10 feet in thickness, 90 feet in length, and flush with the river-bed. They will be capable of holding up 10 feet head of water in flood and 14 feet head of water in summer. At Assiout, Mr. Stephens is the resident engineer of the barrage, which has one hundred and eleven openings of 16 feet, and of the Ibrahimin Canal head, which is to discharge 20,000 cubic feet per second in flood. No one who has not had personal experience of such works can conceive the labour, ingenuity, and skill needed to lay 300,000 square feet of floor in the bed of a river, 16 feet below the water-level, on a sandy foundation honeycombed with springs, whose action is aggravated by each hour of delay. At Zifta, where the barrage has fifty-one openings of 16 feet, Mr. Hurley is the resident engineer. The latter is under Major Brown, Inspector-General of Lower Egypt, while the Assiout Barrage, with the Assuân dam, is under the charge of Mr. A. Webb, Director-General of Reservoirs.

Egypt proper consists of 6,000,000 acres of cultivable land. Of this area, 4,000,000 acres are rented at a mean value of £5 per acre per annum, and 2,000,000 acres at a mean rental of £1 per annum. Practically one-third of the country is undeveloped, because the summer supply of the Nile, which is the keystone of perennial irrigation, is not sufficient. The way in which the Irrigation Department, under the guidance of Sir William Garstin, who succeeded Sir Colin Scott-Moncrieff, has stretched the existing supply by skilful rotations, would make one believe that water was an elastic substance, but the farthest limit has been reached. To develop Egypt as she can be developed, we require reservoirs capable of supplying annually 200,000 millions, or 200 milliards of cubic feet of water. This would mean an additional discharge of 20,000 cubic feet per second in summer, and an increase to the renting value of Egypt of £6,000,000 per annum. This increase would represent a capitalised value of £60,000,000. In other words, each milliard of cubic feet of water supplied to Egypt is worth £300,000.

As the Nile has been at the bottom of everything in Egypt, be it the dethroning of a viceroy to whose charge were laid the disastrous floods of 1877 and 1878, or the success of an occupation, so the disastrous summer supplies of 1888 and 1889 decided the question of reservoirs. Sir Colin Scott-Moncrieff appointed me Director-General of Reservoirs, with four years within which to prepare the projects. The superior staff consisted of Messrs. Hewat, Roux, Clifton, Stent, Rushdy Bey, Hassib Effendi, Saber Effendi, and Balig Effendi. We examined all the sites available in Egypt, and finally decided on the Assuân Cataract as the true site for a reservoir dam. After examining the question in every aspect, I came to the conclusion that no existing dam of any kind would avail on a river like the Nile, with turbid floods of long duration. No ordinary scouring sluices or spill channels would prevent the obliteration of the reservoir in a few years and its conversion into a cultivable plain. I therefore decided on a type of dam hitherto untried, but which I felt confident would meet the requirements. I proposed piercing the dam with openings capable of discharging the whole Nile flood in its strength, and providing these openings with suitable regulating gates, so that the comparatively clear winter waters might be impounded for use in summer. With my mind made up on this point, I travelled over Europe searching for suitable gates. At Bologna I met Signor Benetti, who aided me considerably in my studies, and to whose guidance I subsequently owed much. In Ireland and on the Manchester Ship Canal I at last found the gates which would suit the kind of dam I had proposed, namely, Stoney's self-balanced roller gates. The design could now be proceeded with. The proposed dam was capable of holding up 85 milliards of cubic feet of water, and at the same time passing the maximum Nile floods of 475,000 cubic feet per second.

ASSUÂN DAM: DOWN-STREAM SIDE.



Before proceeding further with the work, Sir William Garstin decided on an International Commission visiting Egypt and giving its opinion on my proposals. The Commission consisted of Sir Benjamin Baker, M. Boulé, and Signor Torricelli. They approved of the site and the type of dam, with reserves about Philæ Temple, which lay on a low island up-stream of the proposed work. They proposed changes in the alignment, which I accepted. The original design followed a crooked line, but rested on the best rock at the cataract. The new alignment was a straight line, cutting off corners. My original line was the better one, and in future works I should strongly advise engineers to sacrifice appearance to good rock wherever they find it. The Commission, especially Signor Torricelli, insisted on very severe conditions of theoretical pressure and stability. These I accepted with avidity, as they enabled me to re-design the dam on much more solid lines, and thus, when the Government, buoyed up by a succession of good summers, yielded weakly to the sentimentalists on the question of Philæ Temple, and insisted on the dam being reduced to a height which would only impound 35 instead of 85 milliards of cubic feet of water, I was able to design a dam which could afterwards be raised and impound 70 milliards of cubic feet of water. The Egyptian Government has a dam at Assuân nominally capable of holding up 35 milliards of cubic feet of water, but actually capable of holding up 70 milliards. These additional 35 milliards of cubic feet of water will be worth £10,000,000, and will be at the disposal of Egypt whenever she wishes to add a few feet to the top of the dam, and spend some £250,000.

The reservoir is described in my report on "Perennial Irrigation and Flood Protection," printed by the Egyptian Government in 1894, and in my report of 1895. It is also given in "Egyptian Irrigation." The Assuân dam is a solid wall of granite masonry, pierced by one hundred and forty under-sluices of 23 feet by 6½ feet, and forty upper-sluices of 11½ feet by 6½ feet. The total area of waterway is 24,000 square feet. The greatest height of dam will be 130 feet, and the final head of water will be 85 feet. The maximum flood of 475,000 cubic feet per second will be discharged at a velocity of 20 feet per second, and ordinary floods at a velocity of 16 feet per second. Of the openings, one hundred and ten will be lined with granite ashlar, and thirty with cast iron. The regulation will be performed by Stoney's self-balanced roller gates. (*See plate.*)

As the International Commission, which controls the finances of Egypt, refused to sanction the funds for building the Assuân dam and the Assiout weir, Lord Cromer arranged with Sir Ernest Cassel, who provided the funds, and, with Sir John Aird & Co. as contractors, and Sir Benjamin Baker as consulting engineer, undertook their completion in five years. The Nile has so far looked kindly on the majestic work which is being built across it, and has given an unprecedented series of good seasons for its timely completion. On my leaving the Egyptian Service, Mr. Wilson was made Director-General of Reservoirs, and on his death, last summer, Mr. Webb took his place. Mr. Maurice Fitzmaurice, the resident engineer, has allowed no questions of expediency or expenditure to interfere with his resolve to reach such rock as he considers suitable; and though his action has added some hundreds of thousands of pounds to the cost of the work, Egypt can only congratulate herself on the expenditure, and on his presence at the dam. Sir John Aird and Co. are represented at Assuân by Mr. John A. C. Blue, another man as hard as the granite he works with.

The dam, if built by Government agency to its full height, would have cost, with all its additional foundation masonry, £1,750,000, and have been capable of impounding 70 milliards of cubic feet of water. Each milliard of cubic feet of water would therefore have cost £25,000, and been worth £300,000. As the schedule of rates by which the contractors are being paid is not in the hands of the public, no estimate of actual cost can be made.

From now on, the whole of Egypt will be gradually changed from basin to perennial irrigation; and we shall be confronted with the very problems which Menes and the Pharaohs of the XIIth Dynasty solved. It would not be unwise to follow their example, and first convert one bank and then the other to perennial irrigation; and when the time came to endow the whole country with the superior class of irrigation, attention might be directed to another depression in the Lybian deserts, which would be to the modern irrigation of Egypt what Lake Mœris was to the ancient. South of the Fayoum lies the depression known as the Wady Rayan, and connected with the name of Mr. Cope Whitehouse. If this were put in communication with the Nile Valley in the same manner as Lake Mœris, I have calculated that an expenditure of £3,000,000 would suffice for the works. It may, however, be found possible to utilise the excess waters of the Atbara River, by the aid of weirs, for the irrigation of extensive tracts which are now desert; and in the same way to utilise the Blue Nile for the Sennaar and Meröe doabs, as we should say in India, or geziras, as they say in the Sudan. It must always be remembered that perennial irrigation requires only one cubic foot per second per 100 acres, while basin irrigation requires five times as much, and consequently, when basin irrigation is finally changed to perennial irrigation, Egypt will be able to dispose of a great part of her flood supplies, and, with suitable weirs and regulating works, be capable of thoroughly developing her new system of irrigation without any fear of inundations.

It was previously stated that Egypt needed 200 milliards of cubic feet of water, and that the Assuân dam could supply 70 milliards. The remaining 130 milliards must come from those vast lakes which constitute the sources of the Nile, and which to-day are in the possession of the English and Egyptian Governments. In a paper entitled "Barrages and Collateral Works on the Nile," published in the Professional Papers of the Corps of Royal Engineers (Vol. XXVI., Paper VII., 1900), and in a pamphlet entitled "The Nile Reservoir Dam at Assuân, and After," just published by Messrs. Spon & Co., I have explained in some detail how much can be done for Egypt by suitable works at the sources of the Nile. I shall here give the veriest outline of works which, in the not distant future, it will be the privilege of the Egyptian engineers to undertake.

If there are no political obstacles in the way, the Dembea or Tsana lake in Abyssinia, at the source of the Blue Nile, with a surface of 1,000 square miles and a reservoir capacity of 200 milliards of cubic feet of water, is a superb site for a reservoir. The water would course down to Egypt, and would be available for the whole of the rich-soiled Sennaar province south of Khartoum. Then we have Lakes Victoria and Albert Nyanza within the Uganda Protectorate, soon to be connected with the coast by a railway. Here we have lakes of 26,000 square miles and 1,500 square miles respectively, with

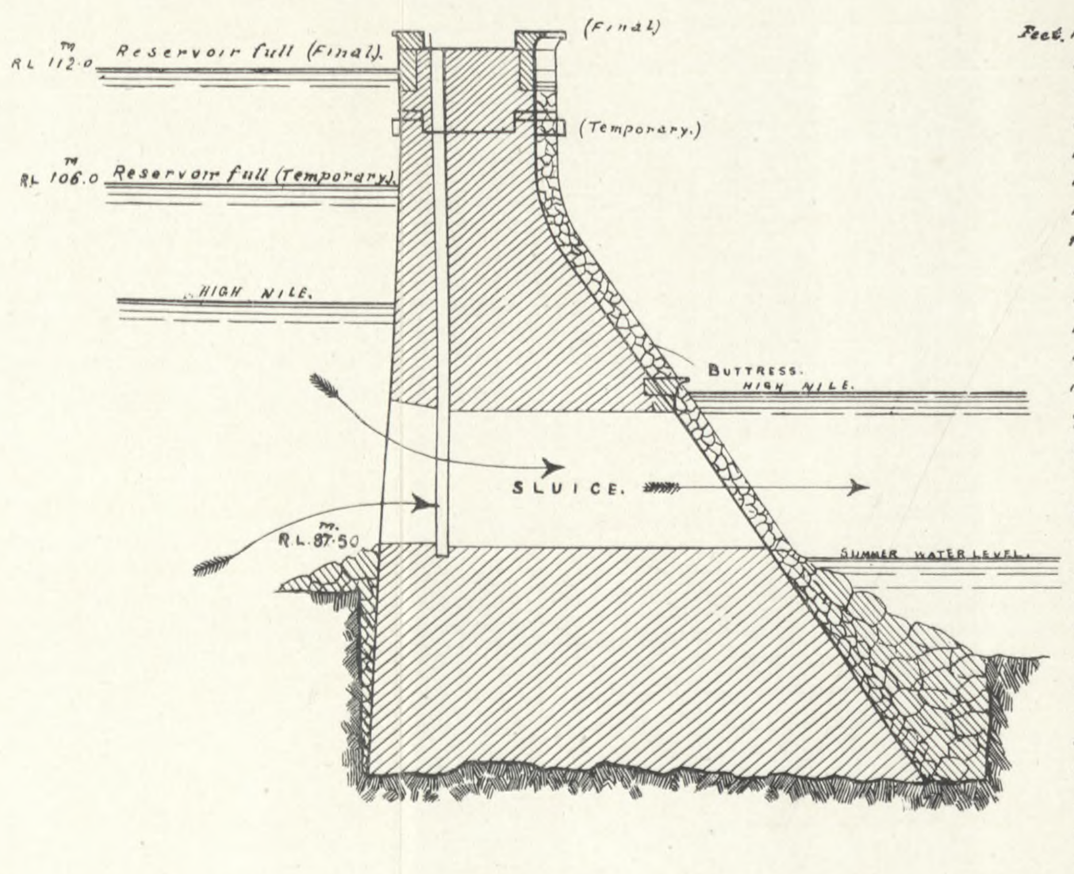
65 Sluices	at R.L.	87·50	Metres above Mean Sea.
75	„ „	92·00	„ „ „ „
18	„ „	96·00	„ „ „ „
22	„ „	100·00	„ „ „ „
TOTAL 180			
Mean High Flood Level at Assuán		92·90	Metres above Mean Sea.
„ Low Water	„ „ „	85·00	„ „ „ „

ASSUÂN DAM.

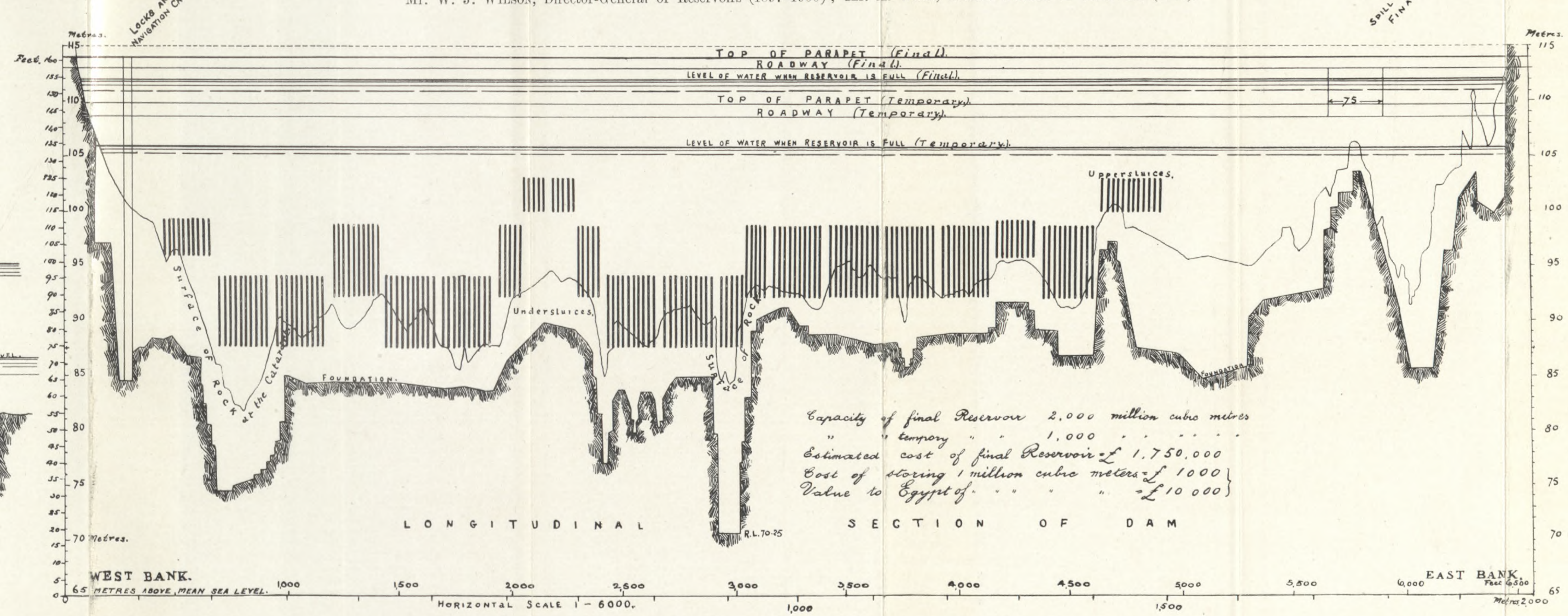
UNDER CONSTRUCTION.

Projected and Designed by Mr. W. WILLCOCKS, Director-General of Reservoirs (1890–1897). Mr. STENT, Head of Drawing Office.

Being built by Mr. MAURICE FITZMAURICE, Resident Engineer-in-Chief; Mr. JOHN A. C. BLUE, Engineer to Messrs. Sir JOHN AIRD & Co., Contractors; Mr. W. J. WILSON, Director-General of Reservoirs (1897–1900); Mr. A. WEBB, Director-General of Reservoirs (1900).



CROSS SECTION.



VERTICAL SCALE AND SCALE FOR CROSS SECTION 1–400.
All Dimensions in Metres.

an immense reservoir capacity. I have contended for years that an expenditure of £1,000,000 would suffice to store enough water in these lakes to meet the requirements of the Nile Valley from Fashoda to the Mediterranean Sea, and to free the Blue Nile in summer for the sole use of the Sennaar province. The one obstacle is the opening of a channel 1,500 feet wide and 15 feet deep through the peat marshes and swamps traversed by the White Nile in the sudd regions, and through which, at an expenditure of £15,000, Sir Reginald Wingate has opened a channel some 100 feet wide. The work executed by Major Peak, which saved Egypt during the low summer of 1900, following the famine year of 1899, and endowed the country with £4,000,000 of cotton, is but the prelude to mighty undertakings in this region, which has been twice visited by Sir William Garstin since the reconquest of the Sudan, and where lies the great public work of the Egyptian Government of the twentieth century. Discharges just taken by Sir William Garstin confirm the statements of all travellers through these dismal regions. It was found that over 10,000 cubic feet per second were lost during the summer of this year. The existing channel was not capacious enough to carry on the outflow of the great lakes towards the north. The time cannot be far off when a score of dredgers at the north end, working southwards, will be cutting broad and deep channels through the poorly consistent peat-growths, which will burn like tinder when brought to the surface, and be scoured out like rubbish when once the waters are confined and have a head on them. Simultaneously with these dredging operations the training of the river will be begun from the south end, which will be carried northwards with the stream. In continuation of the existing banks, wherever they exist, a width of some 2,000 feet having been left for the river, impediments of stakes and brushwood will be run out for lengths of 15 or 20 miles, and all escape channels will be barred. When the muddy waters of the Assua and other right-hand tributaries come down in flood, between May and September, the mud and silt will be caught by the stakes and brushwood, and incipient banks will be begun. On these banks osiers and willows and other plants which love a water-logged soil will be planted. This work will be continued until it meets the dredgers, and then progress will be more rapid. Eventually the Cape to Cairo railway will run on these banks, and a highway will be established through the heart of Africa. The Sudan will then be to Egypt what Nature meant it for, a possession of exceeding great value. No time, however, should be lost. Sir Reginald Wingate should never rest contented till he has under his orders three or four strong brigades of irrigation engineers, examining the country and preparing projects. It may take years to complete the projects; but the sooner they are begun the sooner will they be ready. Eventually the money will be found; and then the well-matured projects which have been prepared without hurry will be put in execution with method and with success already assured. The Sudan is a poor country in itself, but as a highway for the waters of the great lakes it is of inestimable value to Egypt; and when Egypt has realised this and begun to spend her money freely on the great works contemplated in this Paper, then will begin that resurrection of the Nile Valley which will be the crowning glory of the British occupation of Egypt.

DISCUSSION.

Mr. Vernon-Harcourt: A very interesting point is with regard to the volume of water that Mr. Willcocks considers absolutely necessary to secure the summer irrigation of Upper Egypt beyond the storage provided by the lowered Assuân dam. The Author has mentioned a place where it would be possible to get the necessary supply of water, namely, from the Equatorial Lakes. It happens that Mr. Russel Aitken came to me with regard to this question over two years ago; and I have had occasion to go with him into the problem as to the best source for getting the large amount of additional water urgently needed for supplying summer irrigation in Egypt. It is thoroughly acknowledged by the Egyptian Government that the Assuân dam, useful as it may be, even if the reservoir formed by it does not become silted up, as has been prophesied, with the material which comes down the Nile, is not nearly sufficient for the wants of Egypt, especially after it has been lowered so much as to reduce the reservoir capacity by more than one-half. There are only two sources practically available where water can be obtained for the irrigation of Egypt—either the Equatorial Lakes, or what is known as Lake Dembea or Lake Tsana in Abyssinia. Going into the question, I found that Lake Tsana in Abyssinia is at a high level. It is a very large lake, some 1,200 square miles in area, and would therefore, with a very small raising of its waters, store up large quantities of water. Not only is it at a high elevation, but there is also a very uniform fall, as Mr. Willcocks says in his book on "Irrigation in Egypt," down the Blue Nile towards the lower part of the Nile at Khartoum. Therefore you have two advantages in this lake. You have the advantage that you could store up the water in a lake where the lower surface is very large, and where there is a rocky channel at the outlet, and where, therefore, with a dam of very moderate height—20 or 30 feet—you can store up a large volume of water. As far as engineering work is concerned, it gives a prospect of a very satisfactory solution of the problem. The Albert and Victoria Nyanza lakes, though equally good as far as being large reservoirs of water, and capable of storing up a large volume of water by raising their level to a small extent, are not nearly at such a high elevation. It has been lately said by Sir William Garstin, who has written a report on the subject, published in a Blue Book only a month or so ago, that the Albert Nyanza, where the dam would have to be made, was subject to earthquakes; and besides that, what I found, on going into the matter, was that the fall of the White Nile is very small, irregular, and in some places extremely small; and, instead of flowing in a regular channel, it expands over large swamps where the water that was stored up would probably to a great extent be lost, even if the sudd, which obstructs the channel at the present time, were entirely cleared away. Therefore, from an engineering point of view, it would in every respect be more desirable to store up water in Lake Dembea in Abyssinia than in the Equatorial Lakes. I may say that this matter was gone into very thoroughly, and the conclusions I arrived at communicated to Lord Cromer by the Foreign Office, long before Sir William Garstin reported on the subject; and I think it is only just to Mr. Aitken to say that he had proposed Lake Dembea as the proper source long before Sir William Garstin took the matter up and embodied it in his report. The only difficulty with regard to the Lake Dembea scheme is that it is situated in Abyssinia, and political questions might arise; but there seems no particular reason why a lake that is situated in Abyssinia, under proper conditions, should not be made available for the irrigation of Egypt. If the obstacles which might possibly stand in the way of getting a concession for the storing up of the waters of this lake in Abyssinia could be got over, Lake Dembea, so far as our present knowledge goes, would be a far better source, and a far more secure and certain source, than the Equatorial Lakes, with their much smaller elevation, the bad, irregular fall of the White Nile, and also the chance of earthquakes near the dam.

Mr. Wilfrid Stokes: With reference to the sluices of the Assuân dam, the majority of the 180 sluices are 23 feet high and 6½ feet broad. When the lower sluice-gates are being worked there is a pressure of nearly 300 tons against them; and although they weigh a little over 14 tons, and are not counter-balanced in any way, they are so constructed that they can be regulated by one native for slow speeds, or by two natives when working at a quicker rate. It may be said, therefore, that we in England are a step in advance in this matter, as we do not require several electrical horse-power to work the sluices, but we merely require a native to turn a handle. There are four locks in connection with the Assuân dam; and the higher lock-gates, owing to the peculiar circumstance that vessels have to be locked through, whether the reservoir is full or empty, have to be 60 feet high. We are making the lock-gates, and the first gate is now being shipped out from Ipswich. They are of very curious construction, almost too complicated to be explained. They are not like leaf gates, but more like a caisson, except that, instead of being floated, they are hung from the top on a carriage which runs on free rollers. The gate is rolled out on bascule girders; and after the locking process is finished, it is rolled back into the recess, the bascules are raised, and the vessels pass through. To perform these operations by manual labour would require eight men, and would, moreover, be rather slow; and therefore a turbine has been constructed in the dam, working hydraulic pumps, so that the lock-gates and their sluices will be worked by hydraulic power in the usual way.

The Chairman: Mr. Willcocks' Paper begins with a slight sketch of the ancient irrigation of Egypt, and describes how what was begun there 7,000 years ago is now in many places being only restored to what the Egyptians accomplished so long ago. That is a very striking thought, and perhaps I might, with all due respect, utter a word of dissent from what our President said in his interesting speech to-day, when he mentioned that civil engineering began with the Romans. I think those who know Egypt will agree with me that it began in that great nursery of knowledge and intelligence that borders the Nile. As far as we know, there are no works which the Romans carried out which are comparable in magnitude, in scientific knowledge, or in comprehensiveness with those which were carried out by the Egyptians.

Another matter which strikes me is the way in which the object for which the great dam at Assuân was designed has been interfered with by æsthetic considerations. I think it is really almost appalling to realise, as we do from what Mr. Willcocks says, that each milliard cubic feet of storage is worth £300,000 capital value, that 35 milliards of water which could be easily stored will be lost every year, in consequence of æsthetic tenderness for a temple which is exceedingly interesting, but is by no means the finest example of Egyptian architecture. Ten million pounds will be kept away from the inhabitants of Egypt, to whom at any rate we may say the temple belongs, in order to preserve the temple of Philæ, not because the Egyptians want the temple, but because certain artistic gentlemen write letters to newspapers and get up a violent outcry. It does seem to me that in this place, where we meet as engineers, we might enter a solemn protest against this abuse of a very good principle, namely, the respect for the artistic remains of an ancient people. But this is carrying a good thing too far; and it seems almost wicked that these millions of cubic feet of water, required for a teeming population, should be denied to them by irresponsible writers to the newspapers who have an admiration for Egyptian architecture, and go into raptures about a temple which, I think I am right in saying, does not belong to a very high order of architecture as compared with the numerous other remains of Egyptian temples. I am told also that the temple itself would not be destroyed, but only to some extent submerged at particular times of the year. If that be true, I think it is a monstrous thing that the English nation—for we are responsible for it—should have given way to this æsthetic craze and have greatly damaged the utility of the Assuân dam, and thus deprived the people of Egypt of ten million pounds.

Mr. W. Willcocks replied by correspondence as follows: In answer to Mr. Vernon-Harcourt, I may say that the Assuân reservoir will never silt up. Provided the dam holds together, the 180 sluices will insure the reservoir against silt for ever. If at any future time the Egyptian Government cares to stiffen its back and spend £250,000 on raising the dam, it can double the capacity of the reservoir. The difficulty with Lake Dembea is that it is not in English or Egyptian territory. As long ago as 1890 I suggested this lake to the Egyptian Government as an alternative reservoir, but the idea was shelved on political grounds. The ease with which Lake Albert Nyanza can be turned into a magnificent reservoir is shown in detail in my recent work on "The Nile Reservoir Dam at Assuân, and After." Surely no man in this world imagines that a 12-foot-high weir runs any danger from earthquakes, especially African earthquakes!

In answer to Mr. Stokes, I should like to say that the designs for gates and locks are due to the late Mr. F. G. M. Stoney, who took the greatest interest in the dam and worked at it with me for years. If the dam proves a success, great part of the credit will be due to him. I have finally to thank the chairman for his very friendly criticism of my Paper; I only wish that his sturdy common-sense had been possessed by the Egyptian Government when the question of lowering the flag of the dam to that of the temple was under discussion.

(*The Meeting was then adjourned.*)

PROCEEDINGS OF SEPTEMBER 4.

Sir John Wolfe Barry, K.C.B., LL.D., F.R.S., in the Chair.

[Paper.]

PROPOSED INLAND WATERWAY BETWEEN THE BALTIC SEA AND THE WHITE SEA.

By M. V. E. de Timonoff, Professeur à l'Institut des voies de communication, Directeur des voies de communication de la région de St. Pétersbourg, Assoc.M.Inst.C.E.

Summary:—Introduction.—Some hydrographical facts concerning the North-West of Russia.—The Port of St. Petersburg and the Kronstadt Ship Canal.—Scheme of the Author for the opening-up of Lake Ladoga to maritime navigation.—Scheme of the Author for an Inland Waterway between the Baltic Sea and the White Sea.—Conclusions.

Introduction.

The Author, having been invited to draw up a report for the International Engineering Congress of Glasgow on "The Existing Conditions of the Principal Inland Waterways of Russia, and the Improvements Proposed," has endeavoured to deal with this extensive subject in such a way as to keep it within reasonable limits. A description of our principal rivers, such as the Volga, the Dnieper, the Don, the Duna, the Yenesei, the Obi, the Amour, etc., and their systems of connecting canals, with a brief account of the improvements proposed on our navigable system, which extends over a distance of 100,000 kilometres (62,138 miles), would exceed the space generally allowed in a Paper presented to a Congress.

The many interesting articles by Mr. C. H. Moberly, M.Inst.C.E., which have been published in *Engineering*, with drawings and maps, appear to have kept the English public very well informed as to the present condition of the navigable waterways of Russia, and the principal schemes for their improvement. Again, the very fact that a Congress of Civil Engineering is held at one of the chief seaports of the world should give the preference to questions dealing with important maritime waterways. It is to one of these waterways, by which the Author proposes to connect the Baltic and White Seas, that he desires to direct the attention of the members of the Congress.

Some Hydrographical Facts concerning the North-West of Russia.

The north-western territories of Russia can be compared with those of the Great Lakes of North America. A glance at the map of this region (*see map*) will show the similarity at once. The Lakes Ladoga, Onega, Saïma, Ilmen, Peipous, and others, which receive the waters of many important rivers, are situated in the principal low-lying regions. Most of these lakes belong to the basin of the Neva, and form an extensive navigable system.

The superficial area of the basin of the Neva is 288,972·5 square kilometres (111,572·4 square miles).* This immense area comprises lakes of all sizes, several of which are almost inland seas. We need, however, only draw attention to those lakes which, together with the rivers connecting them, form the Baltic branch of the navigable waterway described in this Paper. These are the Lakes Ladoga, Onega and Wygo.

Lake Ladoga has an area of 18,129·5 square kilometres (7,000 square miles), with a coast-line of 1,142 kilometres (709 miles). Its mean level is 16·5 feet above the Baltic sea-level. It is the largest lake in Europe, being three times the size of Lake Wener in Sweden. The greater portion of Lake Ladoga is very deep, in some places over 300 metres (984 feet). Below the inlet of the Neva, however, it becomes very shallow. This portion of the lake is called the Koschkinski roadstead, and it presents a great obstacle to navigation. For over 5 kilometres (3 miles) the channel is sinuous and full of boulders; the average depth is about 7 feet, but it is often as shallow as 5 or even 4 feet, owing to the action of the wind. As the vessels at present navigating Lake Ladoga draw from 9 to 12 feet, the necessity of transhipping goods in the Koschkinski roadstead into barges which can enter the Neva, involves considerable loss of time and money, and is even attended with danger to life. The deepening of the channel at the bar at the inlet of the Neva has, therefore, been under consideration for some considerable time; but the necessary dredging operations have only been commenced since 1900. There are two sets of parallel canals along the southern coast-line of Lake Ladoga. These enable river-boats coming from the Volga, *viâ* the canalised rivers and canals known as the Marie and Tikhvinski, the Volkhoff, and the Msta and Tverza systems, which form a third means of communication between the basins of the Neva and the Volga (Vyshnévolotzki), to enter the Neva without passing through the lake, where the waves might be dangerous. The lake is free from ice during five and a half or six and a half months in the year, and is navigable for a slightly longer period.

Lake Onega has an area of 9,751·1 square kilometres (3,765 square miles), with a coast-line of 1,300 kilometres (807 miles). It is 115 feet above sea-level; and the River Svir carries its overflow into Lake Ladoga. In some parts it is 134 metres (439·52 feet) deep. During the winter the lake is completely frozen over, the ice being thick enough to bear sledges. The lake is covered with ice for a period varying from 206 to 231 days, according to the locality. Lake Onega has a numerous fleet of steamers and sailing ships. Along the southern shore of Lake Onega, there is a lateral canal which is a continuation of the River Vytegra and of the Marie system; this affords a safer means of navigation for inland navigation craft unfitted to encounter the dangers of lake navigation.

Lake Wygo, situated on the dividing ridge between the Baltic and White Sea basins, is 80 kilometres (58 miles) long by 5 to 32 kilometres (3 to 20 miles) wide, and has an area of 929 square kilometres (358·68 square

* The dimensions chiefly in use in Russia, and their French and English equivalents, are as follow: 1 sagène = 2·13356 metres = 7 feet; 1 verst = 500 sagènes = 1·06678 kilometre = 0·66288 mile = 3,500 feet.

miles). This lake really belongs to the White Sea basin, for the Lower Wygo River flows from it into the White Sea. The level of Lake Wygo is at least 300 feet above the level of the White Sea; its depth varies from 2 to 17 metres (6·56 to 55·76 feet).

The three lakes described above indicate the natural route from the Baltic to the White Sea. A glance at the map shows that the greater part of this route, independently of the lakes themselves, consists of very important natural navigable waterways. Thus Lake Ladoga is connected with the Baltic Sea by the River Neva, and with Lake Onega by the River Svir. Again the upper reaches of the River Poventchanka, which flows into the northern end of Lake Onega, are close to the basin of Lake Wygo, which is itself connected with the White Sea by the River Wygo. In fact, with the exception of less than 10 kilometres (6 miles), the whole route from St. Petersburg to the White Sea, a distance of over 900 kilometres (558 miles), is navigable. (*See maps and sections.*) Two of the rivers in the above navigable system have a very large discharge.

The Neva is only 64½ kilometres (40 miles) long. Its depth, which is considerable, varies from 20 to 40 feet throughout the greater portion of its length, and is as much as 59 feet near St. Petersburg. There are very few natural obstacles to navigation. The chief one is a rapid, resulting from a sudden widening of the river-bed, where the depth decreases to about 15 feet. The works necessary to overcome this obstacle, and for several other improvements of minor importance, present no technical difficulties; so that by a comparatively small amount of labour, the whole course of the River Neva could be converted into an excellent navigable waterway, with a good maritime basin for the port of St. Petersburg. Unfortunately, artificial obstacles, the work of man, prevent ships from entering this basin, namely, the two large bridges at St. Petersburg, which will shortly be supplemented by a third. All these bridges have movable spans placed away from the channel near one of the river banks. The opening spans, however, are not wide enough; and the depth of water through them insufficient. It takes a very long time to open them. The bridges are, therefore, only opened during the night, for a comparatively short time; and they only allow of the passage of craft of small tonnage, which are subject to very high tolls and much delay. It is to be hoped, however, that the authorities will no longer disregard the harm done to navigation by having unsuitable bridges, and that the spans through which the traffic passes will be rebuilt in conformity with the best suitable modern designs. The river is navigable at its outlet for a minimum period of 204 days, and a maximum of 276 days, or an average of 233 days per annum.

The Svir has a very large discharge. It is 210 kilometres (130 miles) long, and nowhere less than 1·6 metre (5·25 feet) deep. The channel of the river is generally wide, excepting along a certain length having a sharp fall with rapids, where it narrows down to 60 metres (197 feet). The lower course of the River Svir, below the tributary Iandéba, is deep and quiet. There is a bar of little importance at the mouth of the Svir. To render the Upper Svir and Lake Onega navigable for sea-going craft, it will probably be necessary to adopt locks and weirs.

The Lower or Northern Wygo has a very rapid fall. The difference in level, on a length of 102 kilometres (63 miles), between the exit of the river from Lake Wygo and its mouth in the White Sea, is about 300 feet; and there are several large cataracts along its course. The Wygo is over 300 metres (984 feet) wide, and from 2 to 7 metres (6·56 to 22·96 feet) deep. Having described briefly the principal hydrographical features of the district under consideration, we will now proceed to give as short an account as possible of the large commercial port of St. Petersburg, situated at the entrance of the great maritime waterway from the Baltic to the White Sea.

THE PORT OF ST. PETERSBURG; AND THE KRONSTADT SHIP-CANAL.

In 1703, Peter the Great built St. Petersburg, the new capital of Russia, on the delta of the Neva. The site chosen, very near the sea, was no doubt due to the desire of the Great Czar to place the new capital as near Western Europe as possible, without abandoning the ancient and important navigable inland waterway afforded by the Neva. The prosperity of St. Petersburg, and the rapid development of its port, have long since justified this choice. There were, however, several objections to this site. The low-lying marshy land of the islands of the delta of the Neva, the frequent inundations by the sea, and the distance of the new city from the heart of the country, pointed to the advisability of placing the city further up the Neva; on the other hand, the small depth of water over the bar of the Neva rendered it desirable to locate the capital further down the river.

The chief objection to the site chosen for the port of St. Petersburg, namely, the bar of the Neva, was at once realised; and Peter the Great endeavoured to overcome this. His scheme was to build a lateral canal along the coast of the bay of the Neva, leading into the sea near Kronstadt, a fortress erected upon an island 30 kilometres (18½ miles) from St. Petersburg. To the right of Kronstadt, the sea is deep enough for any ship to anchor. The canal projected by Peter the Great was never carried out; but Kronstadt has, by the force of circumstances, become the trade port of St. Petersburg. Until quite recently, goods for St. Petersburg, or goods exported from St. Petersburg abroad, were transhipped at Kronstadt. Barges for inland navigation and a special fleet of lighters traversed the 30 kilometres (18½ miles) across the bay of the Neva, between St. Petersburg and Kronstadt. These encountered many dangers, and were frequently lost at sea, thus involving considerable waste of time and money. This has had an unfavourable effect upon the trade of the country, more especially as St. Petersburg was for many years the only Russian port on the Baltic. When, however, it was proposed to change the port, many obstacles were encountered. The greatest one was that people had got accustomed to the old system; the business community had come to regard the existing state of things with equanimity, especially as the disadvantages fell upon the consumer; whilst the middlemen, and more particularly the owners of the lighters, indeed, derived large profits from these inconveniences. The uncertainty as to whether a deep ship-canal across the bar of the Neva would be a success was another and no less important objection. The zeal and energy of M. Poutiloff, the promoter of this scheme, combined with the technical skill of the engineers under the direction of MM. Foufaïevski and

Saloft, to whom the Government entrusted the construction of this canal, triumphed over all difficulties. In 1885 the ship-canal from Kronstadt to St. Petersburg was inaugurated with great solemnity. The canal is 22 feet deep, and enables ships drawing 20 to 21 feet to navigate up to the new basin near the entrance to the Neva. The work cost 32,000,000 francs (£1,280,000). Although the result has been so successful, it is far from satisfying the present requirements of trade; vessels of large draught are obliged to stop at Kronstadt. It has therefore been decided, in principle, to increase its depth to 28 feet. The ships, however, which are, or will be, able to navigate this canal cannot enter the Neva, and still less Lake Ladoga. The Neva and Lake Ladoga have nevertheless sea depths; the latter has an extensive coast-line, much mineral wealth, and affords a possibility of extending the waterway right up to the Svir, thus shortening by several days the time taken in conveying goods from the Volga *viâ* the lateral canals. The opening of the lake to maritime navigation is therefore a necessity.

Scheme of the Author for the Opening of Lake Ladoga to Maritime Navigation.

As we have already explained, St. Petersburg is now only accessible to ships drawing 20 to 21 feet. Those drawing 19 to 20 feet cannot enter the Neva above the bridges, on account of the insufficient depth through the opening spans. At some points the channel of the Neva is only 15 feet deep, so that only vessels drawing about 14 feet can reach the upper end of the river. Finally, only barges drawing 5 to 6 feet can enter Lake Ladoga.

In order that vessels drawing 14 feet may enter this lake, a few hundred thousand cubic metres have to be dredged, involving an outlay of barely half a million francs (£20,000). By increasing the expenditure to one million francs (£40,000), the lake could probably be made navigable for ships drawing 20 feet. For this small outlay, Lake Ladoga would become, to all intents and purposes, a part of the Baltic Sea, though it would only be accessible to ships able to pass the bridges at St. Petersburg. The reconstruction of the navigable channels past these bridges is, however, merely a question of time and money, and it should be undertaken without delay, so that ships drawing 28 feet may enter the Neva, this increased depth being already decided upon as regards the Kronstadt ship-canal. A few million francs would cover the cost of the necessary works on the Neva, and at the entrance to Lake Ladoga, to render the latter accessible to ships of that draught. The results of opening Lake Ladoga to maritime navigation would be of great importance and an immediate benefit. The shores of Lake Ladoga are thickly wooded, and richly provided with building stone and iron ore.

Owing to the difficulties of transport, these resources have hardly yet been taken advantage of, although so near St. Petersburg, and within reach of the European markets. Once the obstacle at the entrance to the lake is removed, ships of all nations will be able to enter; and new industries will be started on the shores of the lake, worked by the power to be obtained from the numerous waterfalls at present running to waste. Not only would Russia and St. Petersburg derive advantages from the development of these new industries, but all northern Europe would benefit by it, in view of the increasing difficulties of supplying the large iron and steel works with iron ore. This development would not be confined to Lake Ladoga alone ; its beneficial effects must, and no doubt would, be felt much further up-country, owing to the system of inland waterways connected with Lake Ladoga. We have seen that this lake is connected with the Volga by three systems of rivers and canals. At the present time, the barges navigating on these systems dare not risk the dangers of lake navigation, so that, in order to reach the Neva on the way to St. Petersburg, they have to pass through the lateral canals which run parallel to the lake. This will no longer be necessary when the above improvements are carried out. Sea-going vessels will come up to the mouths of the Svir (Marie system), of the Siass (Tikhvinski system), and of the Volkhoff (Vyschévolotski system), and the transhipment of maritime traffic and inland traffic will take place there. The heavy expense and loss of time entailed in transport by canals alongside the lake will be saved. Many commodities will be cheaper, such as the naphtha products, which are now in such demand for the navies of all countries.

It is very difficult at this stage to estimate all the advantages which will be reaped by national and international commerce from the opening of Lake Ladoga to maritime navigation ; but a very rough estimate suffices to indicate that these advantages will be enormous, and out of all proportion to the slight outlay required for obtaining them.

Scheme of the Author for an Inland Waterway between the Baltic and the White Sea.

The opening of Lake Ladoga to the mercantile marine, though important in itself, would only be the first stage in carrying out the great scheme of connecting the Baltic with the White Sea by means of an inland waterway. (*See maps and sections.*) The two other stages would be : (*a*) to deepen the River Svir and to open Lake Onega to maritime navigation ; (*b*) to connect Lake Onega with the White Sea by means of a ship-canal.

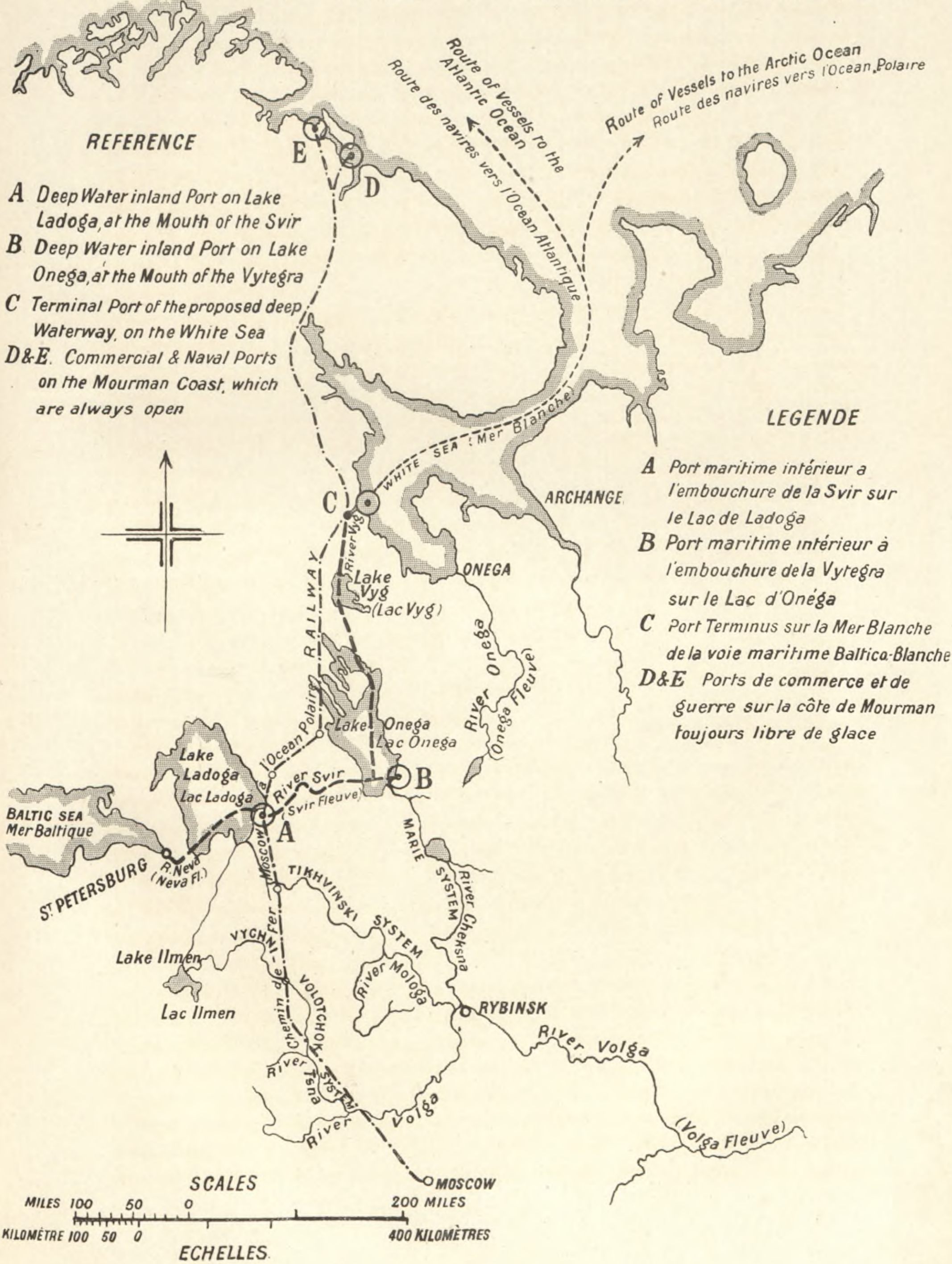
The second stage presents much greater difficulties than the first. It entails the construction of several weirs, with sea locks, on a large and rapid river. But the advantages reaped by opening Lake Onega to international traffic, and by making a seaport at the mouth of the Vytegra, thus shortening the transit of goods on the Volga in river barges by several hundred kilometres, would more than compensate for the cost of the undertaking. Finally, in order to establish maritime communication between Lake Onega and the White Sea, it is necessary to carry out works of the magnitude of those executed for the Manchester Ship Canal, at Kiel and at Corinth, and to embark on a proportionate expenditure. These would, however, be the crowning achievement of the enterprise. The longitudinal section of the projected route gives an idea of the difficulties that have to be surmounted. The idea of connecting Lake Onega with the White Sea by a canal dates far back, and was first contemplated by Peter the Great. About twenty years ago, M. Zdziarski, an engineer, got out designs for a canal of this kind. (*See section.*) It was thought that this canal, intended for river barges, might open markets on the White Sea for agricultural produce coming from the interior of Russia. This commerce, however, seemed to have no prospects of development, and the scheme was abandoned. The Author has taken it up again in quite a new form. It is no longer a question of an inland navigable waterway between

MAP OF NORTH WEST RUSSIA

CARTE DU NORD - OUEST DE LA RUSSIE.

RIVERS AND CONNECTING CANALS & PROPOSED DEEP WATERWAY FROM BALTIC TO WHITE SEA

SYSTÈMES NAVIGABLES RUSSES ET VOIE MARITIME BALTICO-BLANCHE PROJETÉE

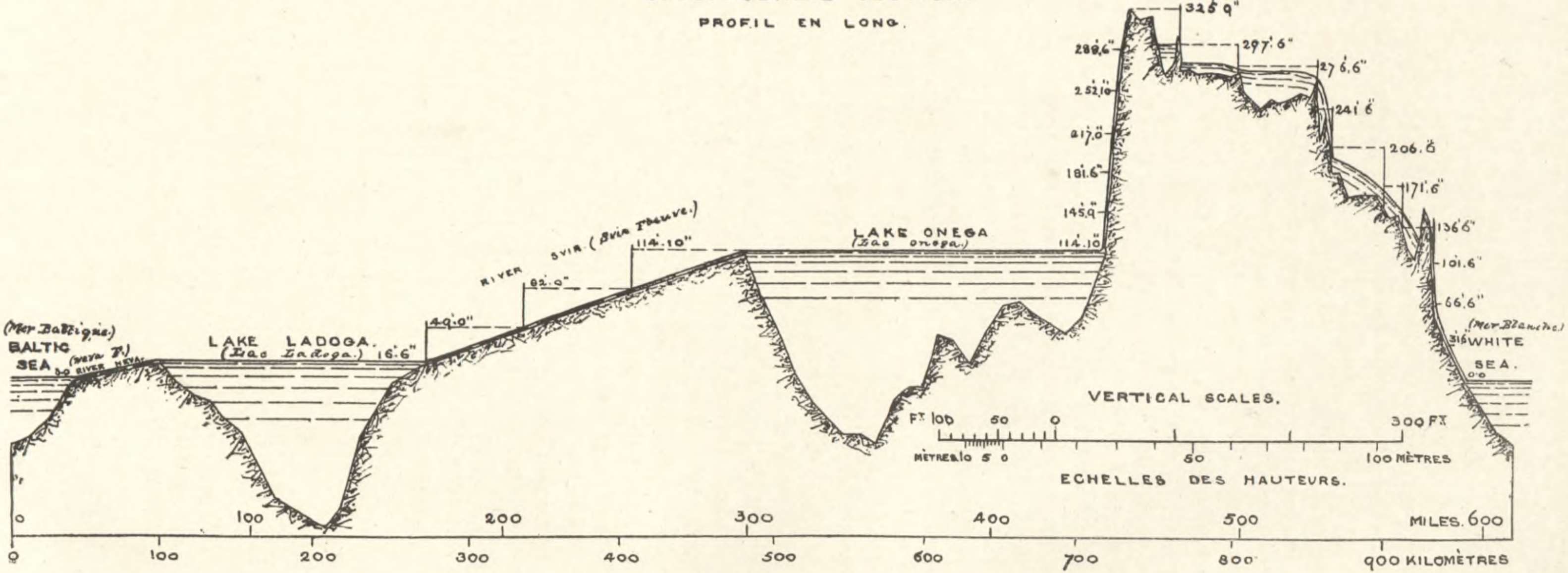


PROPOSED DEEP WATERWAY FOR CONNECTING THE BALTIC AND THE WHITE SEA.

PROJET D'UNE VOIE MARITIME INTÉRIEURE BALTICO – BLANCHE

LONGITUDINAL SECTION.

PROFIL EN LONG.



Lake Onega and the White Sea, but of a deep maritime waterway, extending from the Gulf of Finland to the Arctic Ocean. This waterway would comprise, as we have explained, the River Neva, Lake Ladoga, the River Svir, Lake Onega, and a canal connecting the latter to the White Sea. This canal would, for a great part of its course, utilise the natural navigable waterways. The Neva has sea depths throughout nearly the whole of its course ; ordinary dredging operations in certain shallow places, and especially at the entrance to the river from Lake Ladoga, would render the entire course of the Neva accessible to large sea-going vessels, and would open the whole of Lake Ladoga to maritime navigation. The second stage in the Author's scheme comprises the canalisation of the Svir by means of several weirs and locks ; which would also open Lake Onega, already sufficiently deep, to maritime navigation. Lastly, the works required for cutting through the water-parting between the Baltic and the White Sea would be undertaken.

The scheme also includes the construction of maritime ports on Lake Ladoga at the mouth of the Svir, and on Lake Onega at the mouth of the canalised River Vytegra. These ports, connected with the Volga by an inland waterway (the Marie system), would be the point of transhipment between the maritime traffic and the river traffic of the immense basin of the Volga. The scheme also includes the construction of a railway to connect Moscow, the heart of Russia, with the seaports which it is proposed to build at the outlet of the new canal on the White Sea, and on the coast of the Arctic Ocean near Norway, where the sea is always free from ice.

The Author's scheme fulfils two important objects. In the first place it will give the Russian Navy a freedom of action it does not possess at present, and will thus be the realisation of a very old and long-cherished idea, hitherto attempted without success. The Russian Navy consists of five squadrons, namely, the Pacific Ocean squadron, the Black Sea squadron, the Baltic squadron, the Caspian Sea squadron, and the Arctic Ocean squadron. These squadrons would not generally be able to join forces in time of war, as the outlets of the Black Sea and the Baltic could be easily blockaded, and the principal fleets reduced to inaction. This state of things is the more serious as all the naval shipbuilding yards and arsenals, etc., are actually situated on these inland seas, namely, the Black Sea in the south and Baltic in the north. If the Author's project is carried out, the Baltic fleet will be in a position to steam to any part of the globe at a few days' notice, before any obstacle can be placed to impede it. This will very greatly increase the political influence of Russia. From this point of view, the realisation of the Author's scheme would appear to be the indispensable complement of the Trans-Siberian Railway. The prestige of Russia, and the magnitude of its interests in the Far East, render it imperative that its naval forces should no longer be liable to be imprisoned in the Baltic.

The other object which will be attained by the proposed waterway is the industrial and commercial development of northern Russia. The new waterway will certainly be an important route for conveying to Europe the wood, coal, naphtha, iron ore, and other riches abounding in the northern provinces of Russia. New industries will also be started to develop these resources on the spot. The whole commerce of Europe will benefit by this scheme.

Conclusions.

Although this Paper deals with a special case, it is, nevertheless, one of international importance. The Author, therefore, considers that it will be of interest to state some of the general conclusions which may be deduced from the foregoing remarks.

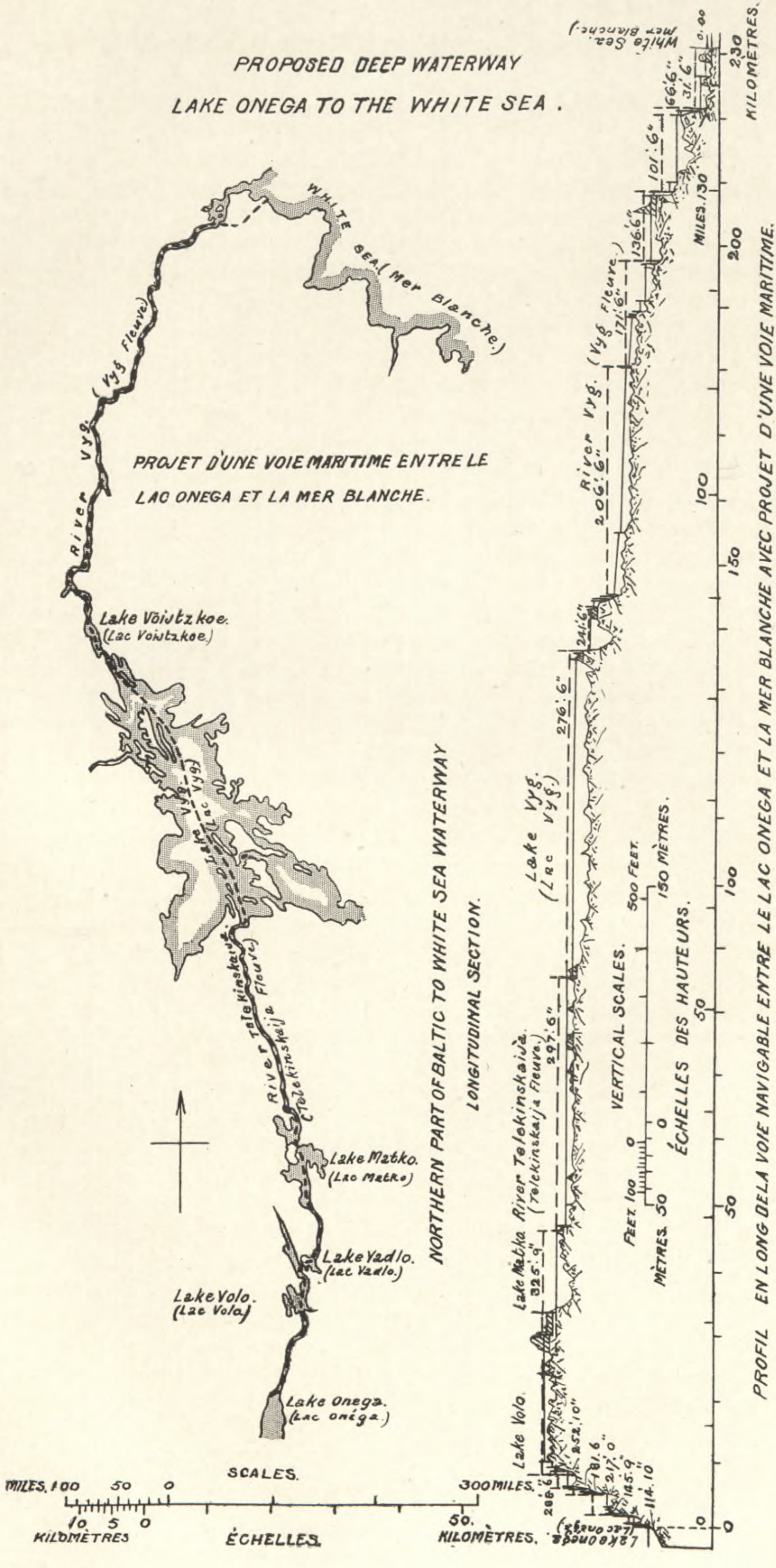
(1) A seaport, situated at the entrance of an important inland waterway, should not be designed and constructed in a manner that may hamper the development of the waterway; furthermore, it is desirable that all possible steps should be taken to avoid the construction of fixed bridges, or, if these are indispensable, the opening spans should be suitably situated, and afford ample width and depth between their piers to provide for all possible future requirements of navigation.

(2) The development of inland waterways, with as great a depth as practicable, should be promoted, so as to enable ships to penetrate into the heart of the country. To bring this about, it is desirable that those great lakes near the sea which have sufficient depths for maritime navigation should first be opened up.

(3) It is desirable that the seas on the coast of the same country should be connected by deep navigable waterways passing through the country. The construction of those waterways, which serve the double purpose of commerce and national defence, should especially be undertaken.

(4) Any scheme for the formation of an inland waterway of sufficient depth to enable shipping to penetrate into the interior, should provide, as far as possible, for the work to be carried out in sections, so that each section, as it is finished, may be capable of being utilised for navigation, without waiting for the final completion of the undertaking.

(5) In Russia, the inland waterway which fulfils the above requirements is the one which would connect the Baltic to the White Sea by way of the great Lakes Ladoga and Onega. The work might be carried out in three sections, the first being the opening of Lake Ladoga to maritime navigation, the second the opening of Lake Onega to maritime navigation, and the third the junction of the two seas. The completion of each of these stages of the work would bring about great industrial and commercial progress to Russia and to the whole of Europe.



PROPOSED DEEP WATERWAY
LAKE ONEGA TO THE WHITE SEA.
PROJET D'UNE VOIE MARITIME ENTRE LE
LAC ONEGA ET LA MER BLANCHE.
WHITE SEA (Mer Blanche)
River Vyg (Vyg Fleuve)
Lake Voivtzkoe. (Lac Voivtzkoe.)
Lake Vyg (Lac Vyg)
River Telekinskaija (Telekinskaija Fleuve)
Lake Matko. (Lac Matko)
Lake Yadlo. (Lac Yadlo.)
Lake Volo. (Lac Volo.)
Lake Onega. (Lac Onega.)
SCALES.
MILES. 100 50 0
300 MILES.
10 5 0
KILOMÈTRES
ÉCHELLES
50.
KILOMÈTRES.
NORTHERN PART OF BALTIC TO WHITE SEA WATERWAY
LONGITUDINAL SECTION.
VERTICAL SCALES.
ÉCHELLES DES HAUTEURS.
FEET 100 50 0 500 FEET.
MÈTRES 50 0 150 MÈTRES.
PROFIL EN LONG DE LA VOIE NAVIGABLE ENTRE LE LAC ONEGA ET LA MER BLANCHE AVEC PROJET D'UNE VOIE MARITIME.
Lake Onega (Lac Onega)
Lake Volo.
Lake Matka
River Telekinskaija (Telekinskaija Fleuve.)
Lake Vyg. (Lac Vyg.)
River Vyg. (Vyg Fleuve.)
White Sea. (Mer Blanche.)
114.10"
145.9"
217.0"
181.6"
252.10"
288.6"
325.9"
297.6"
276.6"
241.6"
206.6"
171.6"
136.6"
101.6"
66.6"
31.6"
0.00
MILES. 130
KILOMÈTRES. 230

DISCUSSION.

Baron QUINETTE DE ROCHEMONT : Je désire présenter une observation générale concernant les conclusions formulées par M. de Timonoff. J'estime qu'elles sont bien formulées, en principe, mais qu'il est difficile de séparer la pratique de la théorie, et dans ces conditions, il ne me paraît pas que le Congrès doive être appelé à se prononcer à ce sujet. D'une façon générale, j'estime que les Congrès ne doivent pas voter de conclusions, sauf dans des cas particuliers et à l'occasion de considérations générales, car il est difficile aux Congrès de prendre des conclusions sur des questions spéciales ; la simple lecture d'un rapport, si intéressant et si complet qu'il soit, en effet ne permet pas de se prononcer en toute connaissance de cause. Pour appuyer ce que je viens de dire, je présenterai quelques courtes observations concernant la troisième conclusion.

Il est incontestable que partout où il est possible de le faire, il est désirable d'appliquer la chose ; mais il ne faut pas perdre de vue que la navigation, et surtout celle de navires de guerre, dans un canal est difficile, tout particulièrement lorsqu'il s'agit, comme dans l'espèce, de monter à une hauteur de plus de 100 mètres. Je reconnais qu'on peut m'objecter que le Canal de Manchester reçoit des navires dans des conditions analogues ; mais il faut remarquer que la hauteur à franchir n'est dans ce cas que de 20 mètres, au lieu de 100 mètres comme dans le Canal de la Baltique à la mer Blanche.

Le gouvernement allemand a fait faire le Canal Kaiser Wilhelm ; mais ce canal n'a qu'une écluse à chaque extremité, et ne reçoit que des bateaux d'un tonnage moindre. Les écluses, les passages rétrécis, et les ponts constituent les points dangereux. La question des ponts, en particulier, est capitale en ce qui concerne la hauteur libre à réserver sous le tablier. Il est admis, d'une façon générale, et je l'ai constaté dans presque tous les ouvrages exécutés en Amérique, qu'il faut réserver une hauteur libre de 150 pieds ou 46 mètres. A l'occasion de la construction projetée d'un pont à l'embouchure de la Seine, les habitants de Rouen ont agi énergiquement afin que la hauteur libre sous le pont soit portée à 55 mètres, et ce chiffre a été admis. Il est vrai qu'il y a sur le Canal de Manchester un pont fixe à hauteur beaucoup moindre, mais c'est là un cas unique qui ne peut être pris comme exemple pour l'avenir.

En dernier lieu, je dois faire remarquer que dans un pays riche et très peuplé, il est difficile, à différents points, d'ouvrir un canal maritime qui comprenne des tranchées profondes. C'est ainsi que dans le Canal des Deux Mers, dont il est question en France, pour réunir la Méditerrannée à l'Océan—canal qui, je l'espère bien, ne sera pas établi—bien qu'il doive y avoir de nombreuses écluses, on prévoit une longue tranchée de plus de 100 mètres de profondeur. Alors même que la largeur au flan d'eau ne serait que de 60 mètres, l'emprise des terrains à cause des talus aurait une largeur considérable, et troublerait toute les communications existantes. Peut-être une telle entreprise est-elle possible dans le pays compris entre l'Onéga et la Mer Blanche ;

mais elle n'est pas admissible dans un pays peuplé, cultivé comme la vallée de la Garonne en France, ou la région qu'aurait dû traverser le Canal reliant la Clyde et le Forth, dont il a été question dans ce pays.

Je termine donc en rappelant ce que j'ai eu l'honneur de dire en commençant. En principe, les conclusions présentées par M. de Timonoff, d'une façon très intéressante, ont mon approbation ; mais j'estime qu'il n'y a pas lieu pour le Congrès de les voter.

Mr. W. H. Hunter : Before going into the subject of the Paper, I wish to speak on the question of the bridges, especially in connection with the Manchester Ship Canal. It is quite true that Runcorn Bridge existed some years before the Manchester Ship Canal was built, and, consequently, that bridge, which crossed the line of the canal, of itself furnished a gauge which limited the headway, and consequently the height of masts of vessels on the canal ; but it is not quite correct to stop at that, because the limiting headway of the Runcorn Bridge above ordinary water-level in the canal is something like 82 or 83 feet, while the limiting headway on the canal itself is 75 feet. That 75 feet was arrived at after much consideration of the difficulties of the railway communications which crossed the canal, and of the question of the masts of ships. From the point of view of the steamers which navigated the canal, I do not think it is too much to say that the headway of 75 feet has never stopped a single steamer from coming to Manchester. In populous counties like Lancashire and Cheshire, it is of importance that roads should be uninterrupted ; but in a district such as that with which Professor de Timonoff is dealing, there is not the slightest difficulty in constructing railway bridges with opening spans. Swing bridges are now made of the simplest and most ordinary construction. We have bridges working on the Ship Canal, with the movable portion weighing 1,700 tons, which are opened and closed without the slightest difficulty in forty-five seconds. Therefore I think Professor de Timonoff's position as to the construction of works may be considered to be established.

When you come to the question as to his third conclusion, namely, the desirability that the seas on the coast of the same country should be connected by deep navigable waterways passing through the country, it is a little difficult to accept that conclusion generally ; although I cannot, with that map of the Clyde before me, but think of what appears to me to be an opportunity lost for carrying this third conclusion into practice in our own country. Some years ago I was connected with the project for uniting the Forth and the Clyde by means of a waterway, which would have enabled the largest ironclad of the fleet to pass from coast to coast of this country. What would that have meant in times of war or threatened war? That seems to me to be a case to which Professor de Timonoff's third conclusion absolutely applies. A very moderate amount of assistance from the Government would have carried that scheme through. It was not necessary for the Government to find the capital ; if it had been prepared to guarantee even the small dividend—2½ per cent. would have been accepted on the capital found—that canal would have been in the course of construction, even if it had not been completed, before now. But the Government of this country—for which no blame attaches to it—tied by public feeling, could do absolutely nothing, and the scheme fell through. It is one of the many—unhappily numerous—examples of the manner in which tradition, and the habits of our forefathers, hinder development and hamper enterprise in this country. Had it been in Russia, Germany, or France, the Government would have constructed the canal.

M. Quinette de Rochemont does not appear to have much sympathy for the project of the Canal des Deux Mers ; but a French Commission, composed of Members of the Legislature appointed by the French Government, were at Manchester only last week or the week before, going over the Manchester Ship Canal in view of the revival of the project of which M. Quinette de Rochemont speaks with such little faith. So far as the first part of this great scheme is concerned—the connection of Lake Ladoga with the sea—there can be no question of its usefulness ; and I am sure we are indebted to Professor de Timonoff for speaking of it here this morning, and for the information he has given us about these Russian lakes and waterways. Some progress with the scheme has been made ; and I hope that it will be pushed through, on account of the enormous resources that are to be found in these northern provinces of Europe, which are practically unavailable at present.

Mr. William Brown : I am very glad to see our old friend Professor de Timonoff here to-day. My firm has been associated very much with his Government, and with him personally, in carrying out very expensive contracts for dredging plant. I cannot speak on the many engineering difficulties which this undertaking may involve ; but it is only fair to say that if dredging can do the work, Professor de Timonoff is a great authority in Russia on that point.

We have constructed about half a million sterling of plant for the Russian Government ; and the dredgers do the work in a most energetic way, working night and day. I have seen some dredgers built for a canal in Russia, where they were dredging in advance, cutting through woods with trees falling in front of the dredger, and I cannot see why a canal of greater length should not be attacked in the same way. It was a remarkable thing to see the trees falling across while the dredging was going on ; and in my opinion, if dredging can do the work, our Russian friends will carry it through.

Mr. S. Mavor : I have listened with very great interest to Professor de Timonoff's Paper, and while being quite incompetent to give any opinion as to the engineering difficulties, I very much question the commercial practicability of his proposed scheme. The advantage of a highway for ocean-going vessels up the River Neva to Ladoga and through the Svir River to Onega is, of course, evident ; but beyond that, the country is undoubtedly a poor one. For hundreds of miles it is covered with forests, and apart from the products of the forests in timber and tar, and of the fisheries of the White Sea and Murman coasts, it is difficult to see what the canal would have to carry. The population is exceedingly sparse in the region through which the canal would pass, and on the northern coasts the population is merely a summer one. There is the further point, that the White Sea is closed for many months of the year ; and I really do not see the possibility of any large commercial development in the Archangel Province of Russia. The present governor, Engelhardt, has been most energetic, and has done great work for the White Sea and the Murman coast by establishing telegraphs all round the coast, and by lending money to the fishermen to enable them to purchase, wholly or partly, the boats they use, and also by keeping a magnificent fleet of steamers on the Murman coast between Archangel and Vardo. But it appears to me that the fleet of steamers he has put on the coast are far too good for the work they have to do. It seems impossible, without a large Government subsidy, that the commercial development of that coast could ever warrant so handsome a fleet of steamers as are now running; nor could the future commerce warrant the construction of the canal now proposed.

The work of the Ministry of Ways of Communication in Russia compels the admiration of everyone who has visited that vast country. The maritime route which passes round Lake Ladoga, and through the Svir River to Onega, and goes as far as Vytegra, by the route Professor de Timonoff proposes, has of recent years had vast sums of money spent upon it for the purpose of enlarging the locks and deepening the canal to provide for barges of much larger tonnage. It appears to me it is to the south-west, towards the densely-populated portion of the country, that increased facilities of water communication should be provided. Around and far south of St. Petersburg the country is under forest, without any ultimate possibility of agricultural development; and it is in the populous regions of Central and Southern Russia, where the growing towns are, that it would be more advantageous to spend money on increased waterway communications.

The question of providing a way for war vessels from the Baltic to the White Sea is a strategic one; but to some extent the necessity for that from a Russian point of view has been reduced by the opening, within the last year or two, of the new ice-free port at Tkaterina harbour on the Murman coast. This ice-free port, however, is subject to certain limitations, the harbour being a small one and extremely remote; and the conformation of the hills around it makes it almost impractical for establishing any extensive arsenals or docks on the site. Without railway communication this harbour cannot attain much political importance; and for commerce it depends upon fisheries alone.

Mr. C. H. Moberly: I have had many favours shown me by Professor de Timonoff during the last few years, and he has given me a great deal of information by correspondence which is very useful and interesting, so that I am sorry to have to differ from him altogether on the subject of this Paper. His project really consists of two parts—the commercial and the strategical. The commercial part means displacing the port of St. Petersburg, or the greater part of it, some hundred miles away, to a place where at present there is practically nothing; there is no town, no business of any kind, at the mouth of the Svir. It is true that nearly the whole of the traffic from the Volga comes down the Svir, and then passes through the canals and down the Neva; and what Professor de Timonoff proposes is that sea-going vessels should be taken up to Lake Ladoga to receive their cargoes, instead of the latter being brought down in barges; I should have thought the expense of constructing a port where there is nothing would be very heavy.

Moving the piers of the bridges in the Neva would be a very serious business, as it is a very swift and deep river, and the bridges were built at great expense; there are two at present, and a third is under construction. I question very much whether the Government would like to face the expenditure of altering those bridges; but supposing they did, what would be the result? The whole or the greater part of the port of St. Petersburg would have to be displaced a hundred miles inland. Professor de Timonoff points out that there has been great difficulty in inducing the commercial world of St. Petersburg to move even to where the canal from Kronstadt to St. Petersburg ends, two miles below the old Custom House and Exchange; perhaps there was a good reason for it. The canal was good enough in itself; but there was a miserable basin, with berths for only eight steamers, which was quite insufficient for the requirements of the port, and steamers had to lie alongside the canal. There is a very large area on one side of the canal which might be dredged, and in that way a very considerable addition could be made to the port of St. Petersburg, and every convenience afforded there; and that would be the right thing to do. Do not attempt to take steamers a hundred miles inland, where you must create a port, or two ports—one at the mouth of the Volkhoff and the other at the mouth of the Svir. The traffic on the Volkhoff is small, because the Government has not developed that canal route properly; but a great deal could be done to improve the route, which would increase business, and at the same time relieve the congestion on the other route. The great complaint of the commercial world at St. Petersburg now is that there is a block on the Ladoga canals. Why is this? There are two canals, and no difficulty should be experienced in keeping them to the depth of six or seven feet; it is true there is a great deal of drift sand there, but I think dredging would remove that. Why not, therefore, spend the money in clearing out and properly working the existing canals, instead of spending millions to force the commercial world to go where they do not want to go? I have a good many friends at St. Petersburg, and I have never heard any one of them say that he wanted to go to Lake Ladoga; but they all complain of the block of traffic on the canals.

With regard to the strategic aspect of the scheme, whether or not it will be an advantage to the Government to take their men-of-war to the White Sea, I do not pretend to know; but I suppose it offers advantages. They want to get to the ocean; but the White Sea is not the ocean. The port Professor de Timonoff proposes in the White Sea is about in the same latitude as Archangel, and the navigation of Archangel lasts about five months in the year. Moreover, the descent to the new port is several hundred feet through canals and locks, and these canals and locks would freeze before the port became ice-bound. It may be argued that ice-breakers could keep them clear; perhaps so, but I should like to mention a very singular fact connected with that. The famous ice-breaker "Yermack" performed great feats in the Gulf of Finland and in the Baltic; she cleared several harbours and released ice-breakers and other vessels. She came to Kronstadt, and it was said in the English papers that she had gone through a thickness of 15 feet of ice. That was very likely pack ice, which is not so hard to break through as frozen ice 2 feet 6 inches thick, which is about the thickness of the Baltic. It was announced that she was going to St. Petersburg in the winter, but she never got there. Why not? I think the reason is very simple; part of the canal between Kronstadt and St. Petersburg is narrow, with a bank on each side, and I do not think she could have forced her way through the ice in it. I think they considered discretion was the better part of valour, and she was not sent on. Therefore, I believe it would be a very difficult matter to keep these canals clear of ice. Supposing they got through, they would have a port which is only open for five months in a year, and that not in the ocean, but only in the White Sea. That can hardly be what they want.

M. de Timonoff : Je n'ai que quelques mots à répondre à M. Quinette de Rochemont, qui m'a fait l'honneur de trouver inattaquables, en principe, les conclusions que j'ai présentées. Il estime qu'elles ne peuvent pas être généralisées et votées par le Congrès. C'est également mon avis et, en les exposant, je n'ai pas eu d'autre intention que de traiter un cas particulier ; et si je me suis permis d'indiquer quelques principes généraux, c'est uniquement pour faciliter la discussion. Je dois donc dire, avec M. Quinette de Rochemont, que le Congrès ne doit pas voter mes conclusions ; et je me hâte de remercier les membres qui ont bien voulu prendre part à la discussion.

Je dois cependant présenter une observation à M. Mavor, qui pense qu'il y aurait peu d'utilité de créer un canal maritime parcourant la partie Nord de la Russie. Il me suffira peut-être de rappeler les objections qui ont été formulées jadis en Angleterre, lorsqu'il s'est agi de la construction du Canal de Suez ; on prétendait que c'était une entreprise absurde. Or, que voyons-nous aujourd'hui ? Ce sont précisément les Anglais qui possèdent presque toutes ou une très grande partie des actions du Canal de Suez ! Cela prouve qu'il est impossible de prévoir avec certitude les changements que la création d'une voie maritime amène dans un pays. Les objections qu'on élève à l'origine n'ont aucune base sérieuse ; des statistiques exactes pourraient seules constituer des éléments sérieux d'appréciation ; or, comme elles doivent être faites sur les résultats acquis avant la création d'un canal, elles sont aléatoires pour l'avenir.

M. Moberly a également soulevé une objection concernant les pertes que subira le commerce de St. Pétersbourg si un port maritime est créé en amont sur le lac Ladoga. C'est là une question très difficile à discuter dans un Congrès, où de rares personnes connaissent la situation ; on peut dire cependant que la création d'un grand centre maritime en amont de Liverpool n'a pas diminué l'importance de cette dernière ville maritime. Vous vous rappelez les luttes parlementaires et autres qui ont agité le pays à ce sujet lorsqu'il s'est agi de créer un port à Manchester ; on a dit qu'il exercerait une influence néfaste sur le port de Liverpool. Or, il n'en a rien été, car toujours la création de ports nouveaux dans un pays augmente son commerce en général, et accroît la puissance des centres maritimes déjà existants. St. Pétersbourg n'a donc rien à craindre d'avoir derrière lui une ligne de côtes de plus de mille kilomètres, où il se créera non seulement un, mais plusieurs ports importants.

The Chairman : It is now my pleasing duty to convey the acknowledgments of this meeting to Professor de Timonoff for his interesting and suggestive Paper ; and I venture to make one or two remarks upon the discussion. One matter which has been alluded to by Professor de Timonoff is the criticisms as to the advisability of making the Suez Canal, which were very rife in this country before the canal was made. As I happen to be connected with the Suez Canal, I may take the opportunity of saying that the objections which were raised against the Suez Canal, from an engineering point of view, were based upon defective data which had been supplied by a survey made several years previously, and which was relied upon as showing that the levels of the Red Sea at Suez and the Mediterranean at Port Said were different; but apart from that, the great commercial success of the Suez Canal has been entirely based upon the great development of steam navigation; if that great development of steam navigation had not taken place, I am bold enough to say that the Suez Canal would have been a commercial failure. If it had had to rely upon the old mode of transit by sailing vessels, there would have been little or no return on the capital; while at present it is one of the most brilliant commercial successes of the whole world. I think that is a circumstance which has arisen since the initiation of the project itself.

There is one other matter I should like to refer to. In this Congress no vote is taken upon any matters which are brought before it. However much we may be in accord with Professor de Timonoff's conclusions, no vote will be taken on the subject; and I do not think in any other of the meetings of the Congress such a course will be adopted. It is rather interesting that this subject of a canal connecting two seas should be brought forward in Scotland, because I daresay many of you know that one of the earliest works for connecting two seas was constructed in Scotland itself; I refer to the Great Caledonian Canal made by Telford, which exists now as a monument to that distinguished engineer, and to the enterprise of our forefathers a hundred years ago. That canal was made for the purpose of connecting the two seas, both for commercial purposes and for the use of ships of war. The work itself was a most extraordinary one at the time it was executed, and it is a very interesting engineering study; but, unfortunately, like many other of these works, it has not been a commercial success, nor has it answered its military purpose. Financially speaking it is worth nothing, and if it were not for the action of the Government in taking over the canal it would have been allowed to go to ruin. For the use of ships of war it was no doubt laid out at the time in agreement with the size supposed to be desirable for the man-of-war of the period; but the latter have altogether outgrown the canal, and it is now practically useless also for that purpose. It is now only kept open at a very considerable annual sacrifice by the British Government. Therefore, one must be a little careful in looking ahead as to the commercial results of this great enterprise now submitted to us, or as to its utility for ships of war. So far as the commercial results are concerned, I should imagine that the northern part of Professor de Timonoff's project would not be very encouraging; the southern part points to much more interesting questions from the commercial point of view. All I can say is that on general principles, and speaking as engineers, it is no doubt very interesting to us to join seas; but the question of cost and of difficulties has to be considered. The natural features of the country seem to point at once to the construction of the work, and I am sure we all wish Professor de Timonoff every success in the prosecution of his enterprise. If the money is forthcoming, it can only result in being of advantage to the country through which it goes, and, of course, also indirectly to the Government he represents. We thank him very heartily for his Paper.

[Paper.]

THE IMPROVEMENT OF THE LOWER MISSISSIPPI RIVER.

By J. A. Ockerson, St. Louis, Mo., U.S.A., Member of the Mississippi River Commission, Member of the American Society of Civil Engineers, Member of the Engineers' Club of St. Louis.

A stream carrying the drainage of an area of 1,256,000 square miles, having 15,000 miles of navigable tributaries, and which is itself 2,500 miles in length, justifies the appellation of "Father of Waters." The Mississippi River, rising in northern Minnesota, where its waters are ice-bound for nearly half the year, flows southward, gathering strength and volume on its way to the sea, until it finally enters the Gulf of Mexico, where it washes the shores of semi-tropical Louisiana. (*See map.*)

The regulation and control of a river of such magnitude involves problems which greatly tax the ingenuity and skill of man to solve. In its lower half the river oscillates in volume from a minimum flow of 65,000 cubic feet per second to a maximum of 2,000,000 cubic feet per second, and the oscillations in stage between extreme high and low water amount to 53 feet. About 1,250 miles above its mouth the Missouri River enters, with its sediment-laden waters that are prolific in hindrances to navigation. This sediment, and that derived from the erosion of the alluvial banks, form the sand-bars which develop during the falling stages of the river, and become at low stages formidable obstructions to navigation. It will thus be seen that there are two distinct problems, one involving the improvement of low-water navigation, and the other the prevention and control of destructive floods. Incidentally, the works executed for the latter have a direct influence on the former, by preventing a dispersion of the waters, and thus inducing a scouring effect in the bed, which enlarges its capacity. The lower half of the stream flows in an alluvial bed of its own formation, the banks of which are very easily eroded. This erosion takes place, for the most part, on falling stages. The banks being composed of alternate layers of sand and silt, or clay, are disintegrated by the layers of sand being washed out when the water in the saturated banks recedes toward the river as it falls. This leaves the clay unsupported, and causes the banks to collapse in large masses, which slide into the river and then disintegrate from the force of the current. In the 885 miles of the river lying below the mouth of the Ohio River, this erosion or caving amounts to an average of 9½ acres in area for each mile of River in a year, or a volume of about 1,003,579 cubic yards for each mile of river per year. The total annual amount of erosion for this reach equals 10 square miles, 86 feet in depth.

In its natural condition the river below the mouth of the Ohio overflowed its banks at flood stages, which generally occur in the spring months. The destructive floods invariably come from the Ohio River and its tributaries, chief among which are the Tennessee and Cumberland Rivers, which drain a region in which the rainfall is exceptionally heavy. The alluvial basin subject to overflow covers an area of about 30,000 square miles. It has a soil of remarkable fertility, which yields enormous crops of cotton and sugar-cane. It is thus capable of sustaining a large population, adding very materially to the wealth of the country. This brief description of the physical conditions of the stream is essential to an understanding of the problems relating to its improvement and the methods employed therein.

From St. Louis to Cairo, a distance of 180 miles, the work projected at present contemplates a channel eight feet deep at low water, and having a width of 2,000 feet. The overflow stages are not of such frequent occurrences as to justify expensive embankments or levees to control the floods. The high stages occur in the months of May and June ; while the low-water season generally begins with September and often extends into the winter months. The system of improvement adopted for this reach consists in contracting the channel and closing side chutes or channels by means of permeable dykes and hurdles. This requires that the banks must be held, which is done by means of revetment. Work is also done with hydraulic dredgers and temporary portable dykes, which are used to open channels through obstructing bars. On the completion of the contraction works now in progress, it is expected that a navigable channel of eight feet in depth at low water will be readily maintained.

The Mississippi River Commission is charged with the survey and study of the physical conditions of the river from its source to the Gulf of Mexico. This survey consists of a chain of high-grade triangulation and a line of precise levels, which form the basis for a topographical survey covering a width of about a mile on either side of the river, and also for a hydrographic survey giving depths, slopes, volume of discharge, etc. Permanent marks or monuments are left at frequent intervals, and these serve as the initial points from which subsequent surveys are made for ascertaining changes occurring in the bed or banks of the river. The general survey, made in great detail, has been nearly completed ; and about 2,000 miles of the river have been mapped, and the maps have been published on a scale of 1 : 20,000.

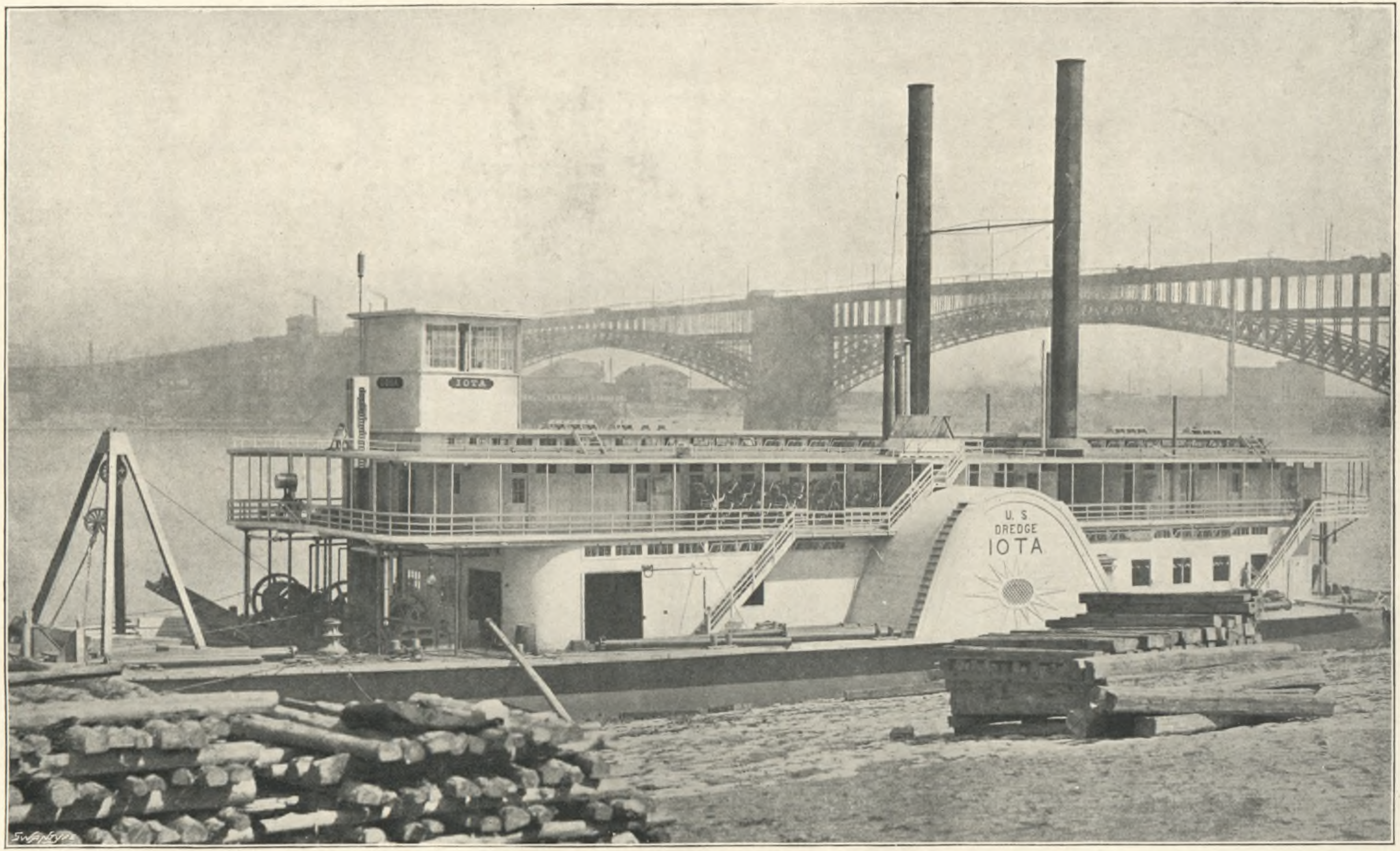
The chief construction work of the Commission has been confined to that portion of the Mississippi River lying between the mouth of the Ohio and New Orleans. The work has consisted of contracting the channel in wide places, revetment, and dredging. A bill pending before the last Congress required that a thorough study shall be made with a view of ascertaining the feasibility and practicability of securing an ample waterway fourteen feet in depth ; the ultimate object being to secure a 14-foot channel from Lake Michigan to the Gulf of Mexico, *viâ* the Illinois and Mississippi Rivers. The present law contemplates a channel not less than nine feet in depth at the lowest stages of the river. Under natural conditions this depth prevails for an average period of about eight months in the year. The low-water period generally ranges from the middle of August to December. This is, however, the period when the grain crops are moving and good navigation is most urgently needed. As the improvement of a stream of such great length will necessarily require a long period of time, temporary expedients for the relief of navigation must be used, for which purpose hydraulic dredgers of large capacity have been constructed. An experimental dredger was first constructed, and worked for a period of over two years, for the purpose of ascertaining whether dredging in a stream where such enormous quantities of material are continually moved along the bed by the current, could give any beneficial results, and also to learn by experience how to manœuvre and operate a dredger and discharge the material in strong currents. These experiments, and work done since then, have fully established the fact that a powerful hydraulic dredger can open an ample navigable channel through an obstructing sand-bar and maintain it at a cost fully justifying the expense. For the next low-water season there will be in the service of the Commission a working fleet of nine dredgers, with a combined working capacity of over 10,000 cubic yards per hour.

A description of one of the later type of dredgers, now under construction, will give a good general idea of what is considered essential to a good dredger, for work in a stream where the material to be moved is river sand. This type of dredger is provided with propelling power operating two side-wheels. The hull is of steel, and ample cabin accommodation for machinery and crew is provided. The general dimensions are as follows:—Length, moulded, 192 feet; width, moulded, 44 feet; depth, moulded, 7 feet; maximum width over wheels, 70 feet; suction well at bow, 25 feet by 33 feet; working draught, 4 feet; cabin, 44 feet by 130 feet; diameter of centrifugal pump, 75 inches; suction and discharge pipes, 32 inches diameter; length of discharge pipe, 500 feet; main engine (tandem compound), 16 and 26 inches by 20 inches; and 7 boilers, with four 11-inch flues, 44 inches in diameter and 30 feet long. The capacity of the dredger is 1,000 cubic yards of sand per hour, delivered through 1,000 feet of discharge pipe, at a pump speed of 160 revolutions per minute. (*See illustration of sand-pump dredger.*)

The sand-pump has a suction on each side of the pump casing; and the discharge leaves the casing from the lower side, and follows along a pipe laid on the lower beams of the hull to the stern, where it is connected with a floating pipe-line. This floating discharge-pipe is carried on pontoons, in lengths of 100 feet, coupled together with flexible joints of rubber, so as to discharge outside of the channel. The discharge pipe-line can be deflected by means of shifting the pontoons, and also by the use of a baffle-plate at the end of the line. The pump runner, 75 inches in diameter, has five blades, and is keyed upon a steel shaft. The blades are provided with removable wearing plates 1¾ inches thick. The casing is of cast iron. The intake of the suction is in two parts, each 11½ feet long by 8½ inches deep. These suction heads are brought down to a section 22 inches square, and enter the hull by means of radial joints, which admit of raising and lowering the suctions at will. This motion is effected by wire ropes passing over sheaves, and operated by suitable winding engines. The material at the suction intake is loosened by water-jets from twelve 2-inch nozzles, working under a pressure of 60 to 120 lbs. per square inch by means of a horizontal duplex compound plunger pump. The main engines are horizontal condensing engines of the tandem compound type, of the dimensions given above. The

HYDRAULIC DREDGER "IOTA."

(Capacity, 1,000 cubic yards per hour.)



boilers are the Mississippi River type, bituminous coal being used as fuel. The dredger is provided with an electric-light plant, refrigerating plant, and steam steering-gear. Ample accommodation is provided for quarters, and for maintaining a double crew. A well-equipped machine shop provides facilities for making all ordinary repairs.

When in operation, the dredger is manipulated by two wire cables, 1 inch in diameter and 1,200 feet long, one end being attached to hauling drums 48 inches in diameter, and the other to hollow iron piling securely placed in the bed of the river. With the cables all paid out, the dredger is at the lower side of the sand-bar to be cut through; and it is pulled up-stream at a speed varying with the depth of the cut and character of material. For depths of 5 feet, the rate of movement ranges from about 90 to 150 feet per hour, or sometimes even as high as 200 feet of cut per hour. After one cut is finished, the hauling cables are shifted, the dredger is again dropped back to the lower edge of the bar, and another cut is made along the side of the first cut. This process is repeated until sufficient width has been obtained. After the first cut has been opened, the current is an active agent in assisting the development of a channel, provided the cut has been properly located with reference to the natural direction of flow. Otherwise, the artificial cut may be filled as fast as it is opened by the material which is moved along by the current.

Where the dredged cuts are properly located, a satisfactory channel can be readily opened; and experience shows that, when once opened, the channel will maintain itself until there is a considerable fluctuation in stage, such as to change the direction of flow of the thread of the current. Such a dredger is operated at a total cost of about $100 (£20 17*s.*) per day of 24 hours.

REVETMENT AND CONTRACTION WORKS.

In a stream flowing through a bed of its own formation the banks are naturally very easily eroded, and a lateral movement in one direction or the other is continually in progress. Any permanent improvement of navigation requires the banks to be made stable, to prevent the flanking of the channel works, and to stop the contribution of eroded material which builds up the obstructing bars. Active bank erosion is confined to the concave sides of the bends in the river, where the thalweg lies close to the bank. These banks are sometimes 50 feet in height above low water, and extend down below for an equal depth. This gives a steep bank about a hundred feet high, which must be protected in such a way as to prevent its erosion and disintegration, a very difficult and expensive work. There is no rock near at hand for use as ballast or paving, and it has to be brought from quarries several hundred miles away. The willows used for covering the bank below the low-water line, grow in profusion along the battures; but even the supply of willows would be severely taxed to meet the demands of a general system of bank revetment. The method now in vogue for holding the banks consists of a covering of fascine willow-mats ballasted with stone and usually 300 feet in width, extending from the low-water line out into the stream. These mats are built and sunk in lengths of about 1,000 feet. The only limit to the length is that fixed by the strength of the head-lines which hold the floating mat in place during construction. With a strong current, and large accumulations of drift, it is often difficult to hold a very long mat.

In the construction of a mat, the first step is to secure the mooring barges end to end at right angles to the shore, and located at the up-stream end of the work. They are firmly fastened together, and cables reaching secure fastenings on shore hold them firmly in position. The heading for the mat is then made of a bundle of strong hard-wood poles, 5 to 8 inches in diameter, and is secured along the down-stream side of the mooring barges to which it is suspended. It is further secured by six or eight wire cables, an inch or more in diameter, passing under the mooring barges, and leading to strong fastenings on shore. To obtain additional strength, a second heading is placed in the mat about 10 feet below the first one, and securely fastened to it. Two mat barges end to end are dropped in below, and parallel to, the mooring barges to which they are attached by three cables, so arranged that the mat barges can be readily dropped down-stream as the mat is built. These barges are built with inclined ways on which the mat is constructed, and are provided with reels for holding the sewing cables and wire strands, all spaced at the proper intervals. Willow poles are next placed in position at the top of the incline, and normal to the shore ; and a fascine, 12 inches thick and 300 feet long, or the full width of the mat, is constructed. The willows used range from 1 to 4 inches in diameter at the butts ; and the entire length, including the bushy tops, is made use of. (*See illustration.*) Galvanised wire cables $\frac{5}{16}$ of an inch in diameter, spaced about 8 feet apart, are attached to the heading, and run the whole length of the mat along its underside. The fascines are drawn close up to the heading, and are fastened together by a $\frac{1}{4}$-inch galvanised wire strand, which passes round each fascine, and also the longitudinal cables which are the mainstays of the mat. The weaving strand and bottom cables are clamped together at frequent intervals by staples driven into the large willows. As the mat ways become filled and the mat develops, the mat barges are dropped away ; and this process is repeated until sufficient length has been made. Rows of large willow poles are placed on top and lengthwise of the mat at intervals of about 16 feet, and are securely fastened in place. These poles perform the double function of strengthening the mat and preventing the loose rock ballast from rolling off. The channel edge of the mat is further strengthened with a $\frac{1}{2}$-inch galvanised steel-wire cable, having a breaking strength of 9 tons. This is clamped to the weaving cable on top of the mat at intervals of 10 feet, the upper end being secured to the heading. Where great strength is required, similar top cables are placed at intervals of 8 to 16 feet, according to the necessities of the case. A mat of the character described can be made at a rate of about 10 feet per hour. When completed, the mat floats on the surface with one side resting against the river bank, the whole being held in place by the mooring lines. (*See illustration.*)

The next step is to sink the mat to the bottom. First a uniform distribution of stone is made all over the mat, and of sufficient quantity to barely allow the mat to float. Barges loaded with ballast stone are then brought to the head of the mat, and sufficient stone is placed thereon to sink it when the lines to the mooring barges are slackened off. The cables to the shore still hold it from moving down-stream. The head of the mat being on the bottom, and the balance still afloat, the stone barges are dropped in below the mooring barges, and parallel to them, and so connected that they can be floated down as the mat sinks. A large force of men then throw off the stone

BANK MATTRESS IN COURSE OF CONSTRUCTION.

COMPLETE BANK MATTRESS, READY FOR SINKING.

on to the mat, and as it sinks the barges float down over it, delivering the stone ballast uniformly until the whole rests securely on the bottom. The head cables, which are provided with special toggles for the purpose, are then removed, and the sub-aqueous portion of the bank is secured by the ballasted mat. The final sinking of a mat 1,000 feet long is accomplished in about an hour.

The form of mat described is found to serve the purpose very well, the weakest point being the wire fastenings, which, in the course of time, corrode and break. When once in place, the ballasted mat filled with sediment will remain, under ordinary conditions, even without fastenings. To obviate the defects incident to corrosion, experiments are being made with silicon bronze and other wires, and different wire coatings.

The following materials are used per 100 square feet of mat:—Willow brush, 1·639 cords; poles, 0·053 cord; steel wire, 4·861 lbs.; silicon bronze, etc., wire, 0·546 lb.; wire strand, 10·965 lbs.; clamps or staples, 1·500; and stone, 0·625 ton. Another form of mat, called a crib mat, is used with good results where the plant is limited, and it also has the advantage of eliminating the use of wire and wire strand. These mats are constructed on temporary ways built on the bank near where the willows are cut. The dimensions are usually 100 feet by 150 feet, and about 1 foot thick; but the mat may be of any suitable size or thickness. A bottom frame of sawn lumber is first laid on the ways, consisting of 2-inch by 4-inch pieces laid in pairs at intervals of 10 feet. Upright posts or binders are placed between the pairs of scantling at intervals of 5 feet, and are secured to them by wooden pins. The first layer of willows is next laid on, and fastened with spikes across the frames, or at right angles to the river; a second layer is laid at right angles to the first, and a third layer parallel to the bottom layer. The whole is then firmly compressed by a special device, and a top frame similar to the lower one is put in place, and securely pinned to the uprights. On top, and across these top frames, poles are fastened, to stiffen the mat while being handled and to hold the ballast in sinking. Each mat as completed is launched into the river; and when a sufficient number have been constructed, they are bound together and towed by a tug or tow-boat to the point required. They can be bound together to form a long mat, or they can be sunk separately. The mat costs three cents ($1\frac{1}{2}d.$) per square foot afloat, and six cents ($3d.$) in place, and requires 12 lbs. of stone per square foot to sink it.

After the sub-aqueous portion of the bank has been securely protected, the upper part of the bank is graded to a slope of 3 to 1 by a hydraulic grader, and the graded surface is paved with stone to a thickness of about 10 inches. This paving is carried up to within 10 feet of the top of the bank, and sometimes is carried right up. Where the ballast stone is very far from the work, artificial stone of cement and river gravel, which is usually near at hand in abundance, is made use of. German Portland cement is used in the proportion of 1 of cement to 13 of sand and gravel. The mixer and its machinery is carried on a tramway laid on the gravel bar where the material is abundant, and a series of moulds are placed on the ground along the tram. The blocks are made 7 inches thick, 12 inches deep, and 6 feet long, and after hardening are broken into sizes to suit. This artificial stone weighs about 140 lbs. per cubic foot. A small plant will make about 160 tons per day, at a cost of about $1.40 (5*s.* 10*d.*) per cubic yard, as against $2 (8*s.* 4*d.*) or more for the stone in some localities.

Experiments are being made with upper bank paving of concrete 4 inches thick laid *in situ.* Brick is also being tried for ballast and paving.

The average cost of a complete bank revetment, with a sub-aqueous mat 300 feet wide and upper bank graded and paved, is $27 (£5 12*s.* 6*d.*) per running foot of bank.

In some cases spur dykes or buttresses, spaced 450 feet apart, have been used to hold high banks and check the erosion, constructed of willows and stone built up in layers on a broad foundation mat. In some places these have failed by scour taking place behind them, as the above-water bank is left unprotected. Such spurs properly spaced would doubtless be successful, and perhaps more economical than the standard continuous revetment. The closure of chutes or side channels is effected by means of brush and stone dams and pile dykes, built to a height somewhat above low water.

Levees.

The alluvial basins below the mouth of the Ohio, which are subject to overflow, cover an area of about 30,000 square miles, or about equal to the area of Scotland. At high stages, these lands, under natural conditions, are flooded to depths varying from a few inches to 15 feet or even more. Originally they were densely wooded ; but the extraordinary fertility of the soil attracted the agriculturist, who settled there and cleared up the lands at the risk of being overwhelmed by the floods. Under such conditions, only the very highest of the lands, which always lie near the river banks, could be utilised ; and most of the land was left in its wild state until the inhabitants undertook to build barriers to keep out the annual floods. In this way the levee system began ; and so long as it was confined to isolated districts, leaving the major portion of the basins still open to the floods, the levees required were of small dimensions.

When the improvement of the river began, it soon became apparent that it was important to confine the waters, as far as practicable, to the same general channel lines at both low and high stages. This meant that the floods must be confined throughout the whole length of the alluvial valley. To restrain all the enormous volume of water necessarily required much higher and stronger levees than had been found sufficient to protect isolated patches of land. As was expected, the river in flood, confined between levees a mile or two apart, reached a plane considerably higher than when it was allowed to spread unimpeded over the wide expanse of basins. While the cause seemed quite apparent, many people attributed the rise in the flood plane between the levees to a filling up of the bed of the stream. This led to an extended investigation by the Author, extending over several hundred miles of river, the conclusion arrived at being that there had been no very decided change in the bed ; but, on the whole, the evidence pointed to a lowering of the bed. This view was further substantiated by the fact that the low-water plane was very materially lower than it was prior to the completion of the levee system, although the depth and volume was equal to those of former years.

Prior to 1882 the construction of levees was confined to the several States and to private landowners. In that year there occurred one of the greatest

WATERSHED OF THE MISSISSIPPI RIVER.

NOTE: The shaded portion along the Lower River represents area overflowed at high water.

floods known, and it became apparent that the aid of the General Government was essential to adequate protection. Appropriations of funds were made; and since that time the Government has spent about sixteen million dollars (£3,300,000) in levee construction, while the several States have spent about double that sum. The total length of levee lines below the mouth of the Ohio is about 1,450 miles; but they still lack much to bring them up to the dimensions and height deemed necessary for safety.

The ordinary standard levee is built with a crown of 8 feet, and side slopes of 3 to 1. The crown and sides are sodded with a very tenacious grass, known as Bermuda grass. Where the levee exceeds a height of 11 feet it is reinforced on the land side with a banquette of earth, which reaches a height of 8 feet below the top of the levee. The crown of the banquette is 20 feet in width, and has a slope, for drainage purposes, of 10 to 1, the side slope being 4 to 1. These dimensions of both levee and banquette are increased if the foundation is bad, or the material is not good. In some places the only material available is a very sandy soil, and in such cases a very large section is required. The use of levees as roadways is strictly prohibited.

On approaching the lower end of the levee system, the floods sometimes continue to stand far up on the levees for several months, which tries them very severely, as they become saturated, and easily abraded by wave-wash from wind or passing steamers. To prevent the wave-wash, a plank revetment is fixed a short distance from the levee. After a levee becomes thoroughly saturated with water, a collapse, with its destructive effects, may occur. Such breaks in the levees are called crevasses. When once formed, they continue to increase in width and the rushing flood plays havoc with everything in its wake. Houses, fences, and even the soil itself are torn up, and great damage is done. When a break occurs, but little can be done beyond holding the broken ends, so as to save as much of the levee as possible. So far, efforts at closing a break have not been very successful, and are always attended with enormous expense. Bank erosion is one of the most active and formidable agents in the destruction of levees. A considerable length of completed line often caves into the river, necessitating the construction of a new line farther back, and connecting with the stable ends of the old line.

The above brief general description of the chief works carried on for the improvement of the Mississippi River will give a fair idea of what is being done. Anything like a detailed account of works of such great magnitude would require volumes; and they have only been touched upon here and there in this Paper. It is hoped, however, that it is not wholly without interest. While this great river has few, if any, parallels, the problems are most intricate and interesting; and their solution will doubtless keep the engineer busy for generations to come. Little by little, step by step, the skill of the engineer will find means of overcoming the difficulties, until finally the great forces of Nature, pent up in the giant stream, will yield to his bidding, and become subservient to the requirements of man. Then will it indeed "flow unvexed to the sea," bearing in safety the commerce of the Mississippi Valley from the Great Lakes to the Gulf of Mexico, from whence it will be distributed to the uttermost parts of the earth.

DISCUSSION.

Mr. C. H. Whiting : It is said that at the present day dredging on the Mississippi is carried out by means of water jets, instead of by mechanical means. That is quite true ; but I believe it is also a fact that since the dredger, which was originally provided with Mr. Bates' cutters, has operated with water jets, the output has not been so great. The Mississippi River Commission feel that they get good results with the water jets, but while the cutters were on the dredgers there were better results than were ever obtained with these water jets.

Mr. W. H. Wheeler : There are two or three points I should like to refer to and ask questions upon. The first is to enquire why more use has not been made of the transporting power of the water, instead of removing the material away ? The Author says : "After the first cut has been opened the current is an active agent in assisting the development of a channel, provided the cut has been properly located with reference to the natural direction of flow." If it will do it partially, why should it not do it to a very much greater extent ? I do not think the transporting power of the water is as much utilised as it might be. I paid a great deal of attention to this subject some few years ago, and for the last few years I have had in operation an eroding dredger, with which I have deepened a number of shallows in a river. The removal of these used to cost something like 1*s.* 6*d.* per cubic yard, but they are now removed for about ¾*d.* per cubic yard ; and this plan has been adopted also in two other rivers I know of, with considerable success. It seems to be a very economical way of deepening a river by stirring up the material and making the water do its own work.

The other point is, why stone is employed instead of clay for weighting the mattresses used for training ? Stone is expensive, and I never use stone now, but employ clay, which is very much better for the purpose. In the Fen rivers we do not usually use large mattresses similar to those in the Mississippi, but we simply adopt fascines, about 6 feet long and 1 foot in diameter, and weight these with clay. I have trained a river having a depth of 20 feet at low water, and a current of four miles an hour, without any trouble, with these fascines, which are very much more easily handled than large mattresses. I am aware that fascines have been tried in this country in one or two places ; and my idea of the reason they were not a success is that the work was not properly done. People think if they throw a few fascines along a river bank they have done all that is necessary, but fascines should be so laid as to hold the earth together ; and the thickness of the intermediate layer of clay should be greater than that of the fascines. Some of the work on the Fen rivers has been done for more than three-quarters of a century. It has to stand the heavy wash of steamers of several thousand tons, and a very large fleet of fishing trawlers which use the river and are always running into the banks. The men, on leaving port, cannot steer very well, and these steam trawlers are continually running into the banks ; but as these are all made of fascines and clay, neither the banks nor the ships are harmed.

Mr. William Brown : It is rather interesting to hear the results obtained on the Mississippi by these dredgers. That form of dredger is not so well known in this country ; and although we construct a great many plants we do not have many hydraulic appliances as described. With regard to Mr. Whiting's remarks as to better work being done by cutters than by water jets, I may say that my firm construct ten or twelve dredgers a year, and never two alike ; and I think engineers here will agree that it is hardly possible to say that one dredger is better than another, for each dredger is made for the local conditions with which it has to deal. It is quite possible that on the Mississippi the water jets are quite good enough, and Mr. Bates may require his cutters for a harder material. With regard to Mr. Bates' system, the results we had brought before us the other day from Queensland were very good indeed, and I hope they will be still maintained, particularly in dealing with dense clay. We are all anxious to know what is the working cost and how the dredgers will do when dealing with clay. It would be hardly fair to carry away the idea that one dredger is better than another, for it is possible to improve on all. Referring to the older system of the bucket dredger, it is only fair to say that very extensive modifications are being carried out in that plant even now. Some members will perhaps corroborate me when I say that we have a dredger on the Otchakoff Canal, in the Black Sea, with buckets of very large capacity—1¾ tons in each bucket—and that dredger loads barges at the rate of 2,000 tons per hour. The horse-power required to dredge this amount is 285 H.P. ; while Mr. Bates' requires 4,000 H.P. to dredge 5,000 tons. The important point is to ascertain the cost per ton of the work.

The Chairman : Do you know the size of the buckets for the new Suez Canal dredger ?

Mr. William Brown : The Suez Canal dredger we built last year loaded herself at about the same rate, and her buckets are each of 32 cubic feet capacity. The dredging rate was 2,000 tons per hour, with an expenditure of 348 H.P. A dredger was mentioned yesterday which did a good amount of work at very small cost. We have dredging plant forty years old now at work. It is quite possible for builders in this country to build a dredger for £7,500 to do 8,000 tons an hour ; but the question is, how long will it maintain that rate of work ?

Mr. C. H. Whiting : I did not intend my remarks to be construed into meaning that the dredger I mentioned on the Mississippi was better than those of Mr. Brown ; but I only wanted to call attention to the fact that after the cutters were suppressed on that particular dredger, it did less work than with the cutters. I was making no invidious comparisons between the dredgers here and those over there.

Mr. Vernon-Harcourt : With regard to the question of the cutters and the water jets, I think one of the reasons why the cutters were suppressed was on account of the trunks of trees, which they call "snags," and other *débris* brought down by the Mississippi. Six or more dredgers have been built for the Mississippi River Commission since the "Beta" ; and they provided them with water jets to suit the special conditions of the

Mississippi, where a great part of the material is sand, and it is therefore found better to employ water jets than cutters ; although possibly, in the case of the " Beta," better results may have been obtained by the cutters in the first instance than subsequently by the water jets. The Report of the Chief of Engineers is published by the War Department of the United States each year, which gives a detailed account of the dredging operations during the low stage of the Mississippi below the confluence of the Ohio ; and it was found, for a particular portion of the river where bars are formed towards the close of each flood season, which are not composed of hard clay but chiefly sand, that the water jets stir up the material sufficiently well and give a better result than the cutters, which are liable to be damaged by any obstacles which may happen to be embedded in the bars.

With regard to what Mr. Wheeler said, I hope I shall be able to get a reply to the discussion from Mr. Ockerson himself, which would, of course, be very much better than anything I could say ; but Mr. Wheeler has advocated the expediency of relying upon erosion by the current of the river. These bars intervene between pools ; and all that the Mississippi River Commission tries to do, by means of the dredgers, is to open up a passage across the bars between the pools, and in that way to form a continuous channel for summer navigation ; and so long as they can cut a narrow passage through, the erosion of the current is relied upon for enlarging the channel. This opening up of channels across the bars is not an operation that may be done one year, and is permanently done ; but it has to be done each year after the abatement of the floods, and has to be done very quickly to provide the necessary available depth for vessels. Therefore, I imagine the engineers in charge of the river are quite right in dredging an initial channel through the bars, and then trusting to a certain extent to the current, which finds its passage of least resistance through this channel, and consequently enlarges it adequately for navigation.

With regard to mattresses, it is well known that in Holland clay is used for sinking the mattresses ; but stone seems to be used on the Mississippi. I can hardly believe that the American engineers would choose stone if clay did quite as well, and if it were cheaper ; but I conclude that there is some adequate reason for the adoption of stone, possibly because they have no clay available, as the soil is mostly alluvial in the neighbourhood of the river. It is highly probable indeed that they cannot obtain clay sufficiently firm, and in sufficient quantities, to sink their mats. Doubtless they get the stone by means of water-carriage down the Mississippi from the rocky strata traversed higher up, and probably, in spite of the long distance, they find it cheaper than clay. Moreover, it is quite possible that the clay, which might be good enough in the Fen rivers, with their very feeble current, would not be sufficiently compact and stiff for a large river like the Mississippi, where clay, if it were not of excellent quality, would be washed away by the powerful current.

The Chairman : I am sure, gentlemen, we all regret very much that Mr. Ockerson is not able to be present to-day to elucidate some of the points raised in his Paper. At the same time, while we regret his absence, I am quite sure you will all accord him a hearty vote of thanks for having submitted the

Paper. The mere statement of the immensity of the problem of the Mississippi is in itself most interesting. When one thinks of a drainage area of one and a half million square miles, and a flooded area equal to the whole of Scotland, one can conceive the gigantic problem which those connected with the Mississippi have to encounter. It is very interesting to engineers to see how the American engineers have adapted local materials to their requirements in the construction of these enormous mattresses. The dimensions appear to be immense, 1,000 feet long and 300 feet wide, amounting, according to my computation, to something like seven acres of ground; and these great mats are made and towed about. Everything connected with the Mississippi has an interest on account of its immensity, and I think that anything brought before us will be received by us with great gratitude. We have to thank the American engineers for giving us the results of their experience; and we are greatly indebted to Mr. Ockerson for his information, whilst we all regret that his engagements have prevented him from attending the Congress.

Mr. J. A. Ockerson replied by correspondence as follows:

I regret very much that I was unable to attend the Engineering Congress and take part in the discussion on the Paper which I had the honour to present. It is very gratifying to have an opportunity to exchange views and experiences with my fellow-engineers in other lands, and I am glad my brief Paper was sufficiently interesting to elicit some inquiry and discussion.

I will endeavour to cover the points raised by the gentlemen who took part in the discussion, which Mr. Vernon-Harcourt has kindly sent to me.

Mr. Whiting says, "While the cutters were on the dredger better results were obtained than were ever obtained with the water jets alone." I am unable to say how he gets his information, but he has certainly been misinformed. A thorough test has been made by the Commission of both cutters of several types and water jets for loosening the material to be dredged, so that it will readily enter the suction pipe and pass on through the discharge pipe. In the material we have to deal with, which is almost invariably coarse river sand with some gravel, the water jet is found to be the most economical and the most effective; it secures in the easiest and best manner a steady flow of as much solid material as the pump can deliver.

In a stream where sunken logs and drift are frequently encountered, cutters and the machinery operating them are often broken, thus causing annoying and expensive delays which are obviated by the use of jets. Cutters increase very largely the number of working parts, many of which are under water, where they are rapidly worn out by the grit with which they are continually in contact. On the dredger in question, there were six pairs of spur wheels and twelve bearings for each pump, or double these numbers in all. This alone is a very serious objection to their use under the conditions found in the Mississippi River. In clay or similar material they are, of course, indispensable to a hydraulic dredger.

The particular dredger referred to by Mr. Whiting was designed by Mr. Bates. It was a magnificent machine of great capacity as it came from his hands. That it had its defects was not surprising, as it was a long way in advance in the matter of capacity over similar dredgers that had been in use up to that time, and it was also to be used under peculiar and unfamiliar conditions. It did not satisfactorily meet the requirements found in actual work, and several changes were therefore made. There was one decided blunder in the design, and that was in regard to the draught of the dredger under working conditions; instead of drawing four and a half feet of water, as required, she actually drew over six feet when completed. This defect was remedied by widening the hull eighteen feet. The hauling and hoisting winches were very complicated and cumbersome, and these were replaced with very much simpler and more effective winches. The cutters were found to be very expensive, owing to breakages and wear and the large amount of power required to operate them. In the meantime, experiments were being carried on with other forms of cutters and with water-jet agitators, resulting in the conclusion that the latter were the best under the conditions met with in our work. The cutters were therefore discarded—not only on this dredger, but on two others—and water jets were substituted. The result of these and several other minor changes is that this great dredger is far more efficient than ever before. Great credit is, of course, due to Mr. Bates for his boldness and skill in designing an efficient machine of such great capacity, and one which under suitable conditions would probably have been entirely successful, although it did not satisfactorily meet the working requirements on this river. The best methods of meeting these requirements could only be developed by experience in actual useful work.

Mr. Wheeler asks why more use is not made of the transporting power of the water, instead of removing the material mechanically; this is very easily explained. The river is a succession of pools separated by sand-bars of varying depths, some of them being obstructions to navigation, while others are not. They are of considerable length, ranging from one thousand to three thousand feet or more. They act in a measure as dams between the successive pools. The energy of the water is dissipated by being scattered over a wide, shallow expanse of river a mile or so in width. Dredging tends to concentrate the volume, and also to cut down the crest of the dam, which of course induces erosion that enlarges the cut. It should further be remembered that there is a never-ending supply of material continually moving along the bed of the stream, in such enormous quantities that the most powerful dredger could at best handle but a small proportion of it. Therefore a cut through the bar is made as quickly as possible, and the current takes possession to carry the loose flowing material through the cut. The bar has been built up particle by particle as the load became too great for the current. This serves to compact the sand, so that after remaining for some time it is less easily eroded. A ditch cut through it with a dredger loosens it up, so that it can again be taken up by the current.

Many types of eroding dredgers have been devised and tried; but they failed to meet the conditions on the Mississippi River for many reasons, among which is the fact that the bars are too long for any stirring or current-deflecting device to be used with success, as the material stirred up would be dropped again in a short distance, long before it reached the pool. In the meantime, the supply, which is always on the move, would rapidly fill the small local space affected by the stirring process. Where the bars are very short and the quantity of material transported along the bed of the stream is small, a stirring process would probably be effective in a measure. As the delivery of the material in floating pipes is a very simple matter in our work, the cost per yard is reduced to such a small figure that it is very doubtful if an eroder could handle it as cheaply. The magnitude of the work required in each case has apparently been underestimated.

Mr. Wheeler wonders why stone is used instead of clay. The Lower Mississippi flows through a bed of its own making, and its banks are therefore composed chiefly of silt and sand. Stone is about as accessible as clay, and is, of course, much better for use in sinking mats. Burned clay or brick is sometimes used on the lower portion of the river, but no suitable raw clay is available. Owing to the great width of bank to be covered, wide mats are a necessity, and as a matter of convenience and economy they are preferably made quite long to obviate the difficulty of making close joints, and avoiding the loss incident to overlapping. In small streams these difficulties would disappear ; but where the stream is from fifty to one hundred feet or more in depth it is impracticable to place single fascines with anything like continuity. The dimensions of the fascine Mr. Wheeler uses are such that it would take fifty of them placed end to end out in the stream to cover the slope, and this would cover only one foot of the length of the bank. Fascines of one hundred feet in length and ten feet in diameter have been tried here with indifferent success. In our mattresses we actually bind the fascines together side by side and sink them as a whole, thus making sure that the bottom will be evenly covered throughout. It may be said here that the manufacture of artificial stone ballast from the sand and gravel mixed with a small amount of cement bids fair to supersede the use of natural stone. In other words, we are endeavouring, as far as practicable, to make economical use of the material at hand on the sand and gravel bars and on the willow islands. On account of the great oscillation in stage, ranging as it does from forty to fifty-three feet, willows cannot be used on that portion of the banks which lies above the low-water line, as they decay very quickly in the warm sun of the southern clime.

A wrong impression seems to prevail as to the large mats. They are always made along the bank which they are to protect, and are sunk there without moving. The large mats could not be towed about, although smaller ones several hundred feet long and one hundred feet wide are often towed down-stream a distance of some two hundred miles or more.

Mr. Vernon-Harcourt's remarks covered the questions raised in the discussion quite fully. I have endeavoured to answer in detail the points that have been raised. In the brief Paper presented, I was necessarily limited to a few general statements as to how this great work is conducted ; and I am very glad of this opportunity to add these few words of explanation, which I trust will be satisfactory.

In closing, I want to express my thanks to the chairman for his complimentary references to my Paper, and to the members who took part in the discussion for their interest in the same.

I shall hope to see many of you at our own great World's Exposition, to be held under the auspices of the Government, in the city of St. Louis in 1903.

[Paper.]

RECENT IMPROVEMENTS EFFECTED IN THE NAVIGABLE CONDITION OF THE SULINA BRANCH AND OUTLET OF THE DANUBE.

By C. H. L. Kühl, M.Inst.C.E., Resident Engineer to the European Commission of the Danube.

The European Commission of the Danube, called into existence by the Treaty of Paris of the 30th March, 1856, is in charge of the Lower Danube from the Black Sea to the head of maritime navigation. (*See chart of Delta of the Danube.*) Training works have been executed at the Sulina mouth and in the Sulina branch, from Sulina to the St. George's Chatal, and also at the Ismail Chatal, where the Toultcha branch leaves the main river. The river from this point to Braila has been surveyed and buoyed, but no works have been constructed, and dredging was only resorted to at Zeglina, above the town of Galatz, in 1893, 1894, and 1895, where a shoal had formed after some abnormal floods, below the confluence of the River Sereth, a wild, sediment-bearing tributary.

The Sulina Branch of the Danube.

In 1856 the depth of the Sulina branch averaged about 8 feet during the low-water season. Beginning from 1857, dredging and training works were undertaken. In 1862 the minimum navigable depth at low water (zero) was 10 feet, increasing to 11 feet in 1863. In 1865 new works were decided on, with the object of increasing the depth to 13 feet at zero, a result which was attained in 1870. The works, including the little M cut with a bottom width of 180 feet and a depth of 16 feet at zero, were finished in 1871. From that time to 1879 funds were only available for the maintenance of the depth already attained, for the correction of five newly-formed shoals, which had to be dealt with to maintain the depth, for widening the little M cut to 260 feet, and for the very successful rectification, by means of training works, of an extensive and dangerous shoal, on which the depth decreased at times to 11½ feet, at the Ismail Chatal.

In 1880 a new series of works, comprising three cuts and training works at Gorgova, over a length of three miles, were commenced, the object being to increase the depth at zero to 15 feet, and to suppress the sharp bends near St. George's Chatal—obstacles offering insuperable difficulties to steamers of great length navigating the river.*

These works were finished in 1886, when the minimum depth was 15 feet at zero. Two more cuts to suppress the sharp bends between the 39th and the 40th mile-post, and at the 38th mile-post, were finished in 1889, when the depth at zero was 16 feet. To gain this increased depth it had been necessary to lengthen the groynes of thirteen old shoals for the purpose of narrowing the upper part of the Sulina branch to 400 feet, and to deal with seven new shoals which had become prominent after the elimination of the old ones. The river bank opposite each system of groynes, and in bends wherever it was subject to scour, was protected by rubble-stone revetments, and prominent points and irregularities of the river bank were removed by dredging and also revetted. The little M cut was deepened to 25 feet at zero, and widened by dredging to 300 feet bottom width, to produce a normal section. The width of the five new cuts dredged from 1880 to 1889 was 300 feet at the bottom, and the depth 16 feet at zero.†

As a sequel, new difficulties arose at the 8½ and 12th mile-post bends, which places gave great trouble to very long steamers on account of the small radius of the curves; and it became evident that these bends, as well as the one at the 18th mile-post, would either have to be eased by three small cuts of greater radius, or would have to be suppressed at a stroke by a long straight cut between the 8th and 18th mile-post. Thanks to the cuts and works in the upper part of the Sulina branch, the depth had been locally much improved, and during floods of even moderate height the minimum depth of the river had been shifted to the lower half of the river, that is below the little M cut.

In 1890 a new series of works between the 23rd and 18th mile-post and the long cut between the 8th and 18th mile-post, suppressing the first or lower loop of the great M, were started, with the object of deepening the river to from 20 to 21 feet at the average summer level—that is, when the water is five feet above zero at the St. George's Chatal—and of removing the difficulties caused by the objectionable bends. Begun in June, 1890, the 8th to 18th mile-post cut was opened in December, 1893. This cut was dredged to a bottom width of 350 feet and a depth of 18 feet at zero.

The groynes between the 23rd and 18th mile-post had been lengthened, and their number supplemented by new ones, to reduce this part of the river to a minimum width of 400 feet. Groynes had also been constructed between the 7th and 8th mile-post and 6th and 7th mile-post, to complete the regulation down-stream. During the four years necessary for dredging this long cut the river had deteriorated rapidly between the 8th

* The tonnage of the largest steamer navigating the river in 1880 was 1,462 net reg. tons.

† The tonnage of the largest steamer navigating the Sulina branch, which was 1,588 net reg. tons in 1887, had increased to 2,197 net reg. tons in 1889, in consequence of the improvements resulting from the cuttings and river works.

and 18th mile-post, and groynes had to be constructed at the 17th mile-post, 12th to 16th mile-post, and 11th mile-post, to give urgent temporary relief.

In the upper part of the Sulina branch no new works had been required, excepting some groynes constructed below the Chatal cut (44th mile-post) in 1891 and 1892, to carry on the regularity in width for some distance below. In response to the facilities afforded by the new cut and works, the tonnage of the largest steamer navigating the Sulina branch increased to 2,674 net reg. tons in 1896.

Again there was trouble, long steamers complaining of the difficult bends below the 35th and above the 33rd mile-posts; in fact, about the whole length of river from the 31½ to the 37th mile-post. A new cut between these two points was started in March, 1894, and opened in October, 1897; its bottom width is dredged to 300 feet, with a depth of 18 feet at zero.

The shoals in the lower part of the Sulina branch, having partly been abolished by the 8th to 18th mile-post cut and partly been improved by new works, groynes, and revetments, the minimum of the river depths during low water had again been shifted to the old shoals of Argagni (41st to 42nd mile-post) and Little Argagni (40th to 41st mile-post). To do away with these shoals and with the bend at the 41st mile-post, another small cut (40½ to 42nd mile-post) was started in August, 1897, and opened in October, 1898. This cut has a bottom width of 300 feet and was dredged to 18 feet at zero.

The size of the largest steamer navigating the Sulina branch has increased (1900) to 2,889 net reg. tons (carrying capacity of 5,900 tons dead-weight).

By the different cuts dredged and works constructed in the Sulina branch since 1880, the river has been shortened by seven nautical miles, and the depth of the Sulina branch has been increased to 17 feet at zero and 20 to 21 feet at the average summer level.

The only bad bends in the Sulina branch which remain and give trouble to long steamers at present are at the 23rd, 24th and 27th mile-posts. These will be done away with by the 18th to 27th mile-post cut, suppressing the second or upper loop of the great M, which was commenced in October, 1898, and will probably be opened in 1902. This cut is being dredged to a bottom width of 320 feet, and a depth of 20 feet at zero. The depth of the Sulina branch will gain 2 feet during the high-water season by the elimination of the shoals between the 18th and 27th mile-post.

When the cutting is opened, the Sulina branch will have been shortened by 11 nautical miles in all, thus reducing its length from 45 miles to 34 miles, from Sulina to the St. George's Chatal. This is in addition to the shortening of 5,790 feet by the little M cut opened in November, 1869, before the new mile-posts were put up.

In the cuts opened from 1880 to 1898, the total quantity dredged and excavated was 21,690,418 cubic yards (Table I.). The cost of dredging in the two last cuts, from 1894 to 1898, about nine millions of cubic yards, was *2d.* per cubic yard, including every expenditure, but exclusive of interest, depreciation and insurance. The quantities dredged are measured by cross-sections. In the new cut 4,863,000 cubic yards have been dredged up to the end of 1900.

TABLE I.—CUTS IN THE SULINA BRANCH OF THE DANUBE.
1880 TO 1900.

Mile-post.	Name.	Year.	Length.	Bottom width.	Depth.	Cubic yards.	Shortening of River.	Number of Bends suppressed.
			feet.	feet.	feet.		feet.	
45–44	Chatal St. George .	1880–1882	3,260	300	16	1,056,974	2,300	2
36	Papadia	1883–1884	2,920	300	16	753,187	1,695	3
43–42	Upper Argagni. .	1885–1886	3,740	300	16	1,218,246	3,555	3
40–39	Lower Argagni. .	1886–1887	2,600	300	16	843,571	595	3
38	Masourale . . .	1888–1889	4,460	300	16	1,232,432	780	2
18–8	Lower half of big M	1890–1893	31,850	350	18	7,682,028	25,675	3
37–31	Gorgova Veniko .	1894–1897	21,800	300	18	6,800,799	8,300	4
42–40½	Argagni	1897–1898	6,500	300	18	2,103,181	1,300	1
			77,130			21,690,418	44,200	21
		Not fin	ished.					
27–18	Upper half of big M	1898–	34,200	320	18		23,275	3

Three dredging machines are employed in the new cuts and for dredging in the river. They work, weather permitting, from the middle of March to the middle of December, when the works are stopped on account of the frost, and the machines are laid up for repairs during the winter. They are open-ended bucket-ladder dredgers, specially constructed to cut their own flotation.

The "Sulina," of 80 I.H.P., built at Trieste in 1866, is fitted with buckets of 7 cubic feet capacity. This machine is used for dredging hard clay and depositing into hopper barges, for forming the slopes under water, and, when fitted with a long shoot, for constructing banks across lakes and low places met with in dredging the cuts across the swamps. The "Sulina" also dredges stones from the old groynes and revetments in the reaches of the river which have been suppressed by the cuts. These stones are used over again for revetting the slopes of the cuttings. The "Delta," of 180 I.H.P., was built in 1881, and the "Hartley," of 250 I.H.P., was built in 1891. These two powerful and efficient dredgers were constructed by the Naval Construction and Armaments Company, Barrow-in-Furness. Both machines are provided with buckets of 17 cubic feet capacity, and fitted with "Burt's" mud-pump, an appliance specially suited for the delta of the Danube, as the banks are nowhere more than 12 feet above the level of the river at low water, which height is within reach of the pump.

The mud-pump delivers the stuff through floating pipes on to the natural banks (and in lakes and low ground behind the artificial banks made by the long shoot), and raises the ground to a height of 2 feet above high-flood level, thus not only forming a dry towing-path, but also disposing of the stuff in a direct, useful, and inexpensive manner. It is mainly owing to the use of "Burt's" mud-pump, which, on Sir Charles Hartley's recommendation, was fitted to the dredger "Sulina" in 1869, that the cost of dredging has been kept extremely low to the present time. When very hard stuff is met with, unsuitable for the mud-pump, the valve is thrown over, and the stuff filled into hopper barges and deposited in the suppressed reaches.

The "Delta" and "Hartley" work day and night with the mud-pumps, and together dredge normally, in the Sulina branch, about two million cubic yards during the average season of 230 working days and the same number of nights. During 1899, working in exceptionally favourable soft clay, they dredged 3,053,753 cubic yards, working 193 days and nights, at an average rate of 1·08*d.* per cubic yard, every charge included except redemption of capital and interest. Reckoning 10 per cent. for these items on the capital value (£36,000) of the two dredgers, that is £3,600 per annum, would give an additional charge of 0·28*d.* for the year 1899, making a total of 1·36*d.* per cubic yard including everything.

The Sulina branch, which was very irregular originally, the width varying from 300 to 800 feet, is now 400 feet wide in the upper part, increasing to 450 and 500 feet in the lower part above the 3rd mile-post. The minimum cross-section in 1880 was 5,162 square feet at zero near the upper end, 1,500 feet below the 44th mile-post. The five cuts made from 1880 to 1889 were dredged to a cross-section of 5,120 feet at zero. These cross-sections have been developed by scour, and the minimum in the upper part of the river is now 6,000 square feet at zero, which increases to 10,000 square feet at zero towards the mouth of the river.

The 8th to 18th mile-post cut was dredged to a cross-section at zero of 6,768 square feet, which has developed to 7,213 square feet minimum. The present cut (18th to 27th mile-post) is being dredged to a cross-section of 6,886 square feet.

For the protection of the river works, groynes, and revetments, steamers of more than 800 net reg. tons are not allowed to navigate at a speed exceeding 8 knots per hour. Smaller steamers can go as fast as they please.

The following table gives the actual depths in the Sulina branch, and the depths reduced to zero on the different shoals in December, 1900:—

TABLE II.

MILE-POSTS.	SHOALS.	DEPTHS. 4th December, 1900. Actual.	Reduced to Zero.
		ft. ins.	ft. ins.
44	Below Chatal cut . . .	24 3	20 2
42	Upper Argagni	21 0	17 0
39	Masourale	24 3	20 5
37	Veniko	21 6	17 10
27–30	Gorgova	21 0	18 1
24–26	Austria	21 6	19 3
18–23	Batmich Kavac	20 0	18 6
8–18	Cut	21 3	20 0
	Average .	21 10	18 11

So far as the navigable depth of the Sulina branch is concerned, the averages of the monthly minimum were :—14 feet 3 inches in 1880 before the cuts and new works were started ; 17 feet 10 inches in 1890 after the opening of the first five cuts ; and 19 feet 3 inches in 1900 after the opening of three more cuts, a gain of 5 feet since 1880.

TABLE III.—NAVIGABLE DEPTHS IN THE SULINA BRANCH.

MONTHLY MINIMUM.

MONTH.	1880.	1890.	1900.
	ft. ins.	ft. ins.	ft. ins.
March	14 9	17 9	18 6
April	16 6	17 6	18 0
May	13 6	18 0	20 6
June	14 6	17 9	21 6
July	14 0	18 0	20 0
August	12 9	18 0	19 3
September	12 0	18 0	19 0
October	14 6	16 6	17 9
November	15 3	17 6	18 3
December	15 0	19 0	20 0
Average .	14 3	17 10	19 3

THE SULINA MOUTH OF THE DANUBE.

In 1856 the usual depth of the Sulina entrance was 9 feet, but during floods this depth often decreased to 7 feet. The provisional jetties, designed and constructed by Sir Charles Hartley, K.C.M.G., the Engineer-in-Chief of the European Commission of the Danube, were commenced in April, 1858, and finished in July, 1861, when the depth was 17½ feet.* (*See survey of Sulina Mouth.*)

After considerable fluctuations, and after the jetties had been consolidated in concrete, the depth varied between 19¾ and 19½ feet in 1871, 20 feet was attained in 1872, 20½ feet in 1873, and after some slight fluctuations in 1876 and 1879, caused by the formation of a bank near the pier-heads during floods, this depth was constantly maintained, by natural scour alone, from 1879 to 1895, without dredging. During high spring floods, the channel between the piers or jetties was scoured to a greater depth ; whereas the depth outside the pier-heads diminished on account of the greater quantity of sediment carried

* A full description of the construction of the provisional piers at Sulina and of their ubsequent consolidation is given in two papers by Sir Charles Hartley on "The Delta of the Danube," Minutes of Proceedings of the Institution of Civil Engineers, vol. xxi. 1862, and vol. xxxvi. 1874.

by the river, and deposited immediately outside. During the winter storms the bank outside was cut down by the sea and littoral current, thus increasing the depth ; whilst on the other hand, the channel between the jetties silted on account of the low water and sluggish current. It was evident therefore that no further improvement in depth could be expected by the action of the jetties alone, which had produced their maximum effect.

From 1883 to 1887, sixty steamers per year on an average had to complete their cargoes in the roads, the depth of 20½ feet of the entrance channel being insufficient for them when fully laden. This number increased to 142 steamers in 1888, 172 in 1889, 207 in 1890, 165 in 1891, and 168 in 1892 ; and as the size of steamers frequenting the Lower Danube was constantly growing, it was plain that the depth of the entrance channel was insufficient. Nothing could be more inconvenient and even dangerous during the autumn and winter months, considering the treacherous character of the Black Sea at these seasons of the year. The loss of time was very great, steamers having been known to have to wait for twenty-six days in the roads, and even then, being overtaken by bad weather, having to leave without completing their cargo.

Sir Charles Hartley, in October, 1893, proposed to the Commission to obtain and maintain the extra depth required by the aid of dredging and by narrowing works between the jetties, a depth of 23 to 24 feet being necessary for the modern class of vessel frequenting the Black Sea ports. A powerful bucket-hopper dredger was ordered in 1893, and interior parallel training-walls were constructed between the jetties in 1894 to reduce the width of the river in that part to 500 feet, and thus by increasing the scour to diminish the quantity to be dredged to maintain the required depth.

The marine dredger "Percy Sanderson," built by Messrs. Wm. Simons & Co., of Renfrew, is 220 feet long, 40 feet broad, and 17 feet 2 inches deep. The hopper carries 1,250 tons. The thirty buckets have each a capacity of 21 cubic feet, and the machine can dredge to a depth of 35 feet. The dredger is propelled by two sets of triple-expansion surface-condensing engines of 1,250 I.H.P. combined, driving twin screws, and giving a speed of 8 knots per hour when the vessel is fully loaded.

The year 1894 being one of extraordinary low water in the Danube, the south bank, opposite the pier-heads, was in an exceptionally favourable condition in the autumn, with 21 feet at zero on the leading line of the Sulina and North Pier Lighthouses. The channel between the jetties, however, had silted up, the depth being reduced to 20 feet at zero. It was consequently necessary to begin dredging the inner channel first, if only to preserve the standard depth of 20½ feet. Dredging the entrance channel between the piers, over a width of 300 feet, was started in October, 1894, the depth being 20½ feet.* (*See survey of Sulina Mouth.*)

In January, 1895, the depth of 22 feet was recorded, the inner channel having been deepened by dredging to 24 feet over one-half the width, and the outer channel being in a favourable condition, as the bank had been further cut down during the winter gales, increasing the depth by 1 foot since October. Dredging the channel between the piers was finished in April, 1895, the work having taken six months to complete. Dredging at

* Survey No. 191, 7–15 Nov., 1894.

sea was started in April, 1895. For the purpose of reaching deep water in the shortest possible way, the channel outside was dredged in a north-easterly direction from the pier-heads, the minimum width being 350 feet, widening to 500 feet seawards. In August, the depth of the entrance channel was 23 feet, and in September, 1895, 24 feet. Dredging operations were brought to a close in October, the outer channel being nearly finished.* (*See survey of Sulina Mouth.*)

The following quantities had been dredged (1894–1895) :—

	Dredging channel.	Maintenance.	Total.
	cub. yds.	cub. yds.	cub. yds.
Between the piers	201,655	5,148	206,803
Outside	202,021	65,069	267,090
Total cub. yds. . . .	403,676	70,217	473,893

The year 1896 was unfavourable, with comparatively high water all the year round, carrying great quantities of sediment; and consequently very little was done to improve the channel, only a small point of original ground left over from last year being dredged. The quantity dredged during the year was :—

	Dredging channel.	Maintenance.	Total.
	cub. yds.	cub. yds.	cub. yds.
Between the piers	—	101,241	101,241
Outside.	16,398	155,426	171,824
Total cub. yds. . . .	16,398	256,667	273,065

The dredger worked from March 27th to December 31st.† (*See survey of Sulina Mouth.*)

The year 1897 was more unfavourable still, the river being open (not frozen over) the whole winter 1896–97, the highest flood ever known coming down the river, bringing down quantities of sand. The depth outside was 23½ feet, from March 6th to April 17th, 1897, before the dredger could remove the new bank. After that date 24 feet was constantly maintained. No improvement by dredging new ground was possible, and the dredger had enough to do to deal with the fresh deposit :—

	Maintenance.
	Cub. yds.
Between the piers	22,102
Outside	265,222
Total cub. yds.	287,324

The dredging operations lasted from January 1st to October 7th.‡ (*See survey of Sulina Mouth.*)

The year 1898 was favourable, with a moderate spring flood, and small

* Survey No. 205, 25 Nov.–3 Dec., 1895. † Survey No. 211, 2–6 Nov., 1896.
‡ Survey No. 226, 14–15 Nov., 1897.

quantities of detritus carried in suspension. The following quantities were dredged :—

	Dredging channel.	Maintenance.	Total.
	Cub. yds.	Cub. yds.	Cub. yds.
Between the piers	—	14,259	14,259
Outside	143,306	168,259	311,565
Total cub. yds. . . .	143,306	182,518	325,824

The dredger worked from April 22nd to November 30th.* (*See survey of Sulina Mouth.*)

The bank to the north of the dredged channel outside, which had increased during 1897, was entirely removed, thus freeing the channel, and at the same time removing an obstruction which had prevented the littoral current, coming from the north, from impinging direct upon the artificial channel and helping to keep it open by pushing the detritus to the south.

The year 1899 was still more favourable, as there were no floods and consequently but little sediment. Between the piers, however, considerable low-water deposit took place, and had to be dredged in order to keep the channel clear. Outside no deposit was dredged ; the channel, however, was straightened by two points to about E.N.E. by dredging away the bank to the south.

The following quantities were dredged :—

	Dredging channel.	Maintenance.	Total.
	cub. yds.	cub. yds.	cub. yds.
Between the piers	—	67,019	67,019
Outside	363,611	—	363,611
Total cub. yds.			430,630

The dredger worked from June 1 to November 30.† (*See survey of Sulina Mouth.*)

Old Sulina Light and North Pier Light in line is again the direction of the channel outside, the traditional line of olden days. The width of the channel to the south of this line being only 300 feet, it will be convenient, when there is a suitable opportunity, to dredge another strip to the south, with a view of increasing the facility of navigating the entrance channel during northerly gales, and providing at the same time a convenient place for deposit to the south of the leading line, when the river brings down large quantities of sediment during floods.

The year 1900 was remarkable for high but clear water to the end of June, when considerable deposit of pure sand took place in the outer channel. The following quantities were dredged :—

	Dredging channel.	Maintenance.	Total.
	cub. yds.	cub. yds.	cub. yds.
Between the piers	—	14,259	14,259
Outside	60,726	142,419	203,145
Total cub. yds. . . .	60,726	156,678	217,404

* Survey No. 231, 2–30 Nov., 1898. † Survey No. 234, 1–4 Nov., 1899.

The dredger started work on July 2 and had removed the new bank by October 31.* (*See survey of Sulina Mouth.*)

Given the character of the Danube, a sediment-bearing river, subject to great floods and changes, slight diminutions in depth are always possible when banks are formed so suddenly that the dredger cannot overcome them at once. Hitherto, however, the dredger has proved powerful enough, not only to maintain the required depth, but to improve the entrance channel besides. The original bank dredged outside in 1895, 1898, and 1899 consisted of clay, and was easily removed. The fresh deposit consists of pure or silty sand, pure in the run of the current near the pier-heads, but mixed with more and more silt the farther away it settles outside. The flood deposit of sand, if not removed by dredging, would be entirely cleared away by the combined action of the gales from N.E. to N. and the littoral current during the next winter. The core of the bank, low-water deposit consisting of clay, is not subject to attrition either by sea or current, which caused the bank to develop and extend constantly before it was artificially dealt with by dredging. The dredger works from sunrise to sunset; by preference only during the summer months, but also in winter when absolutely necessary.

When dredging in soft clay, six loads per day can generally be dredged, and discharged at a distance of three nautical miles, during the summer; thus:—

	Per load. hrs. mins.		Per load. hrs. mins.
Dredging	1 0	6 loads at 2^h 40^m	16 0
Transport	1 10	From and to anchorage	0 30
Mooring and unmooring	0 30		
Total	2 40	Total	16 30

On one occasion seven loads were removed during one day of seventeen and a half hours. The shortest time for filling the hopper has been fifty-five minutes. Dredging sand deposit in the channel, only four loads per day can be removed under favourable circumstances; thus:—

	hrs. mins.		hrs. mins.
Dredging	2 0	4 loads at 3^h 40^m	14 40
Transport and discharge	1 10	Dredger in and out of port	1 20
Mooring and unmooring	0 30		
Total	3 40	Total	16 0

The success of dredging at sea depends principally upon the weather, though the "Percy Sanderson," being of great size, can work in a moderate seaway with waves up to 3 feet high, when not on the beam.

Regarding the element of cost, the quality of the stuff to be dredged is the most important factor, and a shallow cut on an uneven bottom naturally gives very unfavourable results. At Sulina, the worst year was 1896, when the cost of dredging, transporting, and discharging sand and silt was 5*d.* per cubic yard. The best year was 1899, when the cost with clay only came to 2·1*d.* per cubic yard. The average price is 4·2*d.* per cubic yard for dredging, etc., 1,790,736 cubic yards from 1894 to 1899, including all expenditures for

* Survey No. 239, 20–25 Nov., 1900.

repairs, renewals, and liberal maintenance of the dredger, but excluding interest, depreciation, and insurance. Tables IV., V. and VI. give all the details concerning the dredging operations.

The dredger "Percy Sanderson" is fitted with an experimental sand-pump driven by an independent engine of 300 I.H.P. This pump was tried on the bank outside the pier-heads, but the material pumped up would not settle or stop in the hopper, being too fine. When tried, however, on an old sea beach, which crosses the Sulina branch at the 13th mile-post, where there is clean and freely-feeding sand, the suction pump filled the hopper with sand in 1½ hours.

The result to navigation of dredging and maintaining a deep channel is as follows:—

In 1893 . 336 Steamers had to complete their cargoes in the roads.
„ 1894 . 257 „ „ „ „
„ 1895 . 46 „ „ „ „
„ 1896 . 16 „ „ „ „
„ 1897 . 4 „ „ „ „
„ 1898 . 8 „ „ „ „
„ 1899 . 4 „ „ „ „
„ 1900 . 7 „ „ „ „

This is very satisfactory, as it is impossible to provide an extra depth for a few steamers of great draught quite unsuitable for the trade.

It should be noted at the same time that the largest steamer loading in the port of Sulina in 1892 was of 2,190 net reg. tons; the size has greatly increased since that time, and in 1900 the largest steamer was of 3,519 net reg. tons, (6,500 tons dead-weight).

TABLE IV.—DREDGER "PERCY SANDERSON."

NUMBER OF LOADS DREDGED AND REMOVED PER MONTH.

MONTH.	1894.	1895.	1896.	1897.	1898.	1899.	1900.
January	...	37	...	14	...	...	...
February	...	40	...	3	...	...	...
March	...	55	5	41	...	...	...
April	...	32	12	39	18	...	...
May	...	60	36	57	74	...	...
June	...	64	40	49	79	110	...
July	...	85	57	84	79	113	76
August	...	60	54	55	77	108	61
September	...	67	86	53	45	92	86
October	42	29	42	8	45	88	82
November	30	...	30	...	40	93	...
December	59	...	21	...	...	...	...
	131	529	383	403	457	604	305

TABLE V.—DREDGER "PERCY SANDERSON."

QUANTITIES DREDGED IN THE SULINA ENTRANCE CHANNEL.

Year.	Between the Piers.		At Sea.		Total.
	Old Ground.	New Deposit.	Old Bank.	New Deposit.	
	Cubic Yards.	Cubic Yards.	Cubic Yards.	Cubic Yards.	Cubic Yards.
1894	109,070	...	...	...	109,070
1895	92,585	5,148	202,021	65,069	364,823
1896	...	101,241	16,398	155,426	273,065
1897	...	22,102	...	265,222	287,324
1898	...	14,259	143,306	168,259	325,824
1899	...	67,019	363,611	...	430,630
1900	...	14,259	60,726	142,419	217,404
	201,655	224,028	786,062	796,395	2,008,140

DREDGING CHANNEL.

Between piers	201,655	Cubic Yards.
Outside	786,062	
		987,717
1895–1900. Maintenance six years:—		
Between piers	224,028	
Outside	796,395	
		1,020,423
Total cub. yds.		2,008,140

TABLE VI.—DREDGER "PERCY SANDERSON."

DREDGING SULINA ENTRANCE CHANNEL.

Years.	Working. Full Days.	Working. Parts of Days.	Working. Total Days.	Under Steam. hours.	Under Steam. min.	Actually Dredging. hours.	Actually Dredging. min.	Total Quantity Dredged. cub. yds.	Quantity Dredged per Working Day. cub.yds.	Quantity Dredged per Hour at Work. cb. yds	Remarks.
1894	36	18	54	900	10	192	30	109,070	2,020	567	Clay.
1895	153	43	196	3,546	20	1,058	17	364,823	1,861	345	Clay and sand.
1896	129	34	163	3,090	10	967	10	273,065	1,675	282	Sand and silt.
1897	129	41	170	2,921	40	1,113	45	287,324	1,690	258	Sand and silt.
1898	114	32	146	2,401	20	917	35	325,824	2,232	355	Clay and sand.
1899	114	25	139	2,271	50	843	45	430,630	3,098	510	Clay.
1900	67	25	92	1,428	5	543	50	217,454	1,823	308	Sand and silt.

DREDGER "PERCY SANDERSON."

(Cost £38,423.)

COST OF DREDGING, REPAIRS AND MAINTENANCE OF DREDGER, SPARE GEAR, ETC.

Quantity Dredged.

1894 to 1899—1,790,736 cubic yards.

Dredging	Coal and stores	0·81*d*.	2·05*d*.
	Crew and wages	1·24*d*.	
Repairs, etc.	Coal and stores	1·02*d*.	2·17*d*.
	Crew and wages	1·15*d*.	
Total per cubic yard dredging and repairs			4.22*d*.

(Interest, depreciation, and insurance not included.)

N.B.—By measuring the cross-sections it has been ascertained that the dredger removes 713 cubic yards, on an average, per load.

CHART

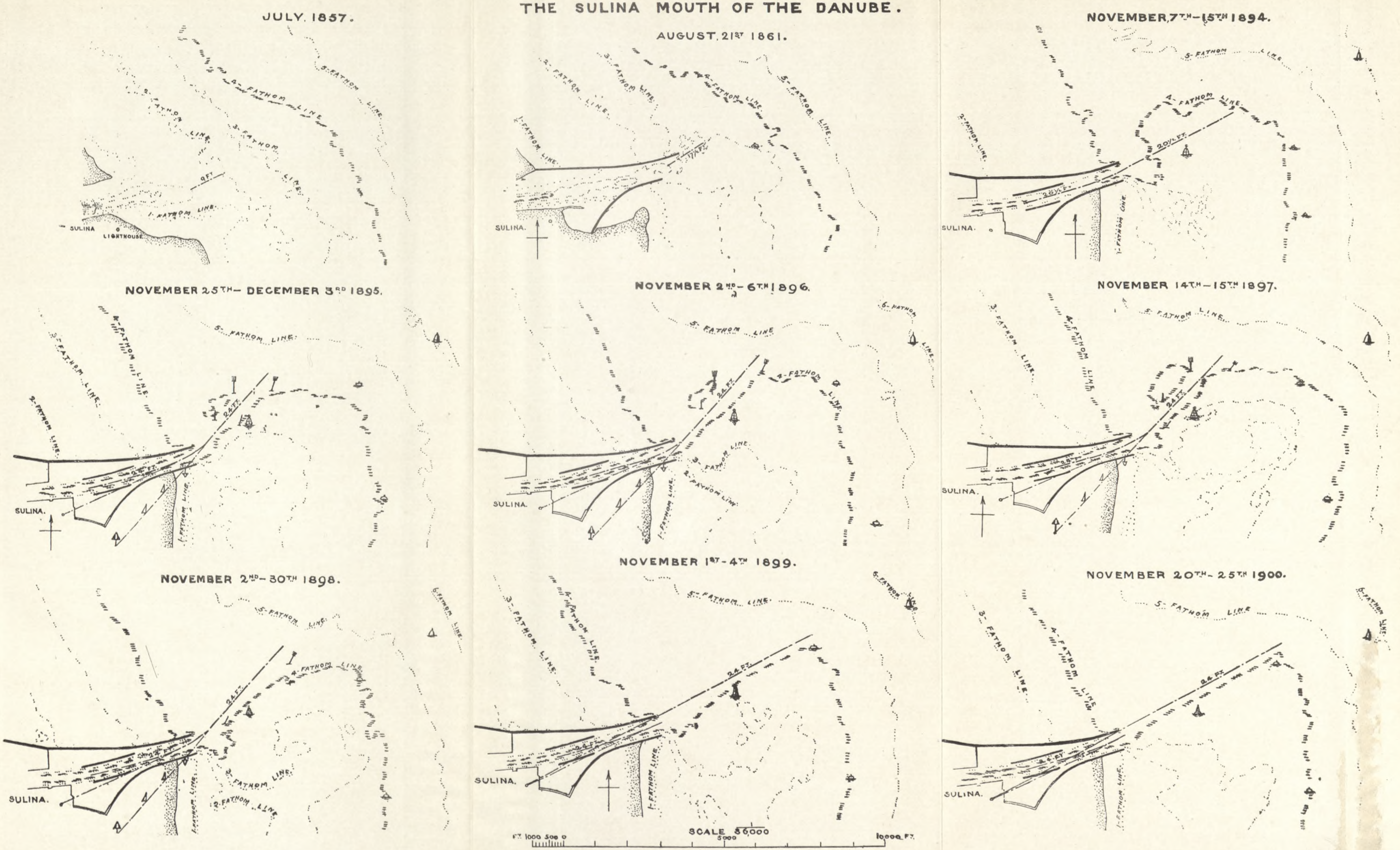
OF THE

DANUBE AND ITS BRANCHES

BETWEEN BRAILA AND THE SEA, 1870–71.

CORRECTIONS 1886 AND 1899.

THE SULINA MOUTH OF THE DANUBE.



DISCUSSION.

M. Vander Vin : Je désirerais savoir si la profondeur se maintient, non à l'embouchure, mais dans la coupure qui est en alignement complètement droit ?

Mr. Vernon-Harcourt : Je crois bien que oui.

M. Vander Vin : Ne relève-t-on pas un profil différent sensiblement de celui qu'on se proposait de realiser ?

Mr. Vernon-Harcourt : On fait des dragages, et cela suffit, paraît-il, pour maintenir la profondeur.

Mr. W. H. Hunter : While the Paper is a broad, useful *résumé* of the work done upon the Danube, and especially upon the Sulina branch, there is not a very great deal in it which lends itself to discussion by persons, like myself, who have no actual acquaintance with the work ; but there is one point which is at any rate interesting as showing the extraordinary difference of experience —actual everyday working experience—which appears to obtain in different parts of this earth. I refer especially to the paragraph which states that "for the protection of the river works, groynes and revetments, steamers of more than 800 net registered tons are not allowed to navigate at a speed exceeding 8 knots an hour"—that would be, roughly speaking, steamers carrying from 1,600 to 2,000 tons dead-weight capacity. Then the next sentence appears to me to be a most remarkable one : "Smaller steamers can go as fast as they please" ; my experience, which is a lengthy one, and which is a matter of everyday work, points in exactly the opposite direction. A few days ago I was in a comparatively small launch, and I passed two or three steamers ; I passed a vessel of the size suggested here, carrying about 2,000 tons. The disturbance was definite and distinct on the surface of the water ; the launch in which I was travelling rolled and tossed, but there was nothing special. I passed a steamer carrying something like 6,000 or 8,000 tons, and the effect was almost imperceptible ; I passed a tug impelled by a single screw, not a paddle tug, and although the tug had sufficient consideration for the house-mark on the funnel of the launch to slow down somewhat, by the time we had got into the middle of the wave caused by the tug, I felt it to be a comfort that my life was insured. There is no comparison, so far as my experience goes—and the conditions of my work are very much those obtaining on the Danube—between the wave caused by a tug running at any rate and that made by a steamer carrying 2,000 tons moving at 8 knots an hour. The smaller steamers will go at any pace you like, from 8 to 14 miles an hour, and they will pile up a wave that no ocean steamer can possibly produce. I can only express my astonishment that experience should have led the engineer at the Sulina mouth of the Danube in an exactly opposite direction to that in which mine has led me.

The Chairman : In the first place I may say that here again we must regret that the Author of the Paper is not present, but it may interest you to know that the gentleman who was kind enough to point to the diagrams was his son. I have been trying to get him to offer a few remarks ; but Mr. Kühl, Junr., has not been at Sulina for about eight or nine years, and he naturally feels that so much has taken place since he was there, that he is unwilling to intrude any remarks on the discussion, because the chief interest lies in what has occurred precisely during the period he has been away.

When I first took the chair at this Section, I said I considered it was peculiarly of an international character, and I may remind those present that the three last Papers have their origin, one in Russia, one in the United States, and the present one in Roumania; so that I think these three are, at any rate, good examples of the international character of this particular Section of the Congress, and of the way in which we are dealing with problems of interest to every nation of the world. In this instance the Paper before us has a special interest, because the works on the Danube originated from an International Commission which commenced its labours at the conclusion of the Crimean War. That International Commission has been of the very greatest benefit to the commerce of the world, and it is a very happy circumstance that it has been able to carry on its work without interruption, and, without any national predilections or jealousies, with one object in view, namely, the improvement of the great waterway of the Danube, which is the granary of Europe. The International Commission of the Danube is to that extent somewhat different from some of the Concerts of Europe that we have heard of in other places; and we may fervently hope that its example may be followed in other cases where the great European nations are interested in the development of the arts of peace and of the commerce of the world. This feeling is not sufficiently prevalent in all countries; there is too little of the international view and too much of private interests.

Here let me say that it is a matter of great interest to me personally that this Paper should be read, because one of my dearest friends has been the Engineer-in-Chief to the International Commission ever since its origin—I allude to Sir Charles Hartley, whose name is well known all over Great Britain, and, I may say, almost in all parts of the world, as one of the most distinguished engineers in this particular branch. I know no one whose name carries so much weight, and whose judgment is so entirely reliable, as that of Sir Charles Hartley. It is a matter of great congratulation that the International Commission was fortunate enough to secure his services; for it required no little skill and no little firmness to insist that the Sulina mouth was the one which ought to be treated, because, on looking at the map, many people may have been led away by the far more important systems which are shown north and south of Sulina, the Kilia mouth and the St. George's mouth, and the selection might have been in favour of one of those rather than the Sulina mouth. I know, from conversations I have had with Sir Charles Hartley, that great pressure was put upon him in favour of each of those two mouths; but he stood firm, and insisted upon operations being commenced at the Sulina mouth; and I think everybody must realise that the results, obtained at a comparatively small cost at Sulina, could never have been achieved at either of the other mouths of the Danube. The success of the provisional works of Sir Charles Hartley, when the amount of money at his disposal was very little, inspired confidence in him; and trade increased to such an extent that the funds became more considerable. The result was that about eight or ten years ago the great problem of dredging was thoroughly taken in hand, and I think the work at Sulina is an interesting example of what has been possible for engineers charged with waterways to accomplish in consequence of the development of the modern dredger.

All or very many of these great works depend almost entirely upon the development of dredger plant which has taken place within quite modern times. If we look back twenty years on what it was possible for engineers to effect in a large waterway or at sea, we can see that the works which we admire could not have been in existence now under the old limitations of dredging plant. For example, dredging in the open sea is a matter of comparatively modern experience; we used to be able to dredge with small dredgers in the rivers, but to dredge in the open sea and in bad weather was considered impossible. The great work of the Suez Canal could never be maintained at its present depth if it were not for the great development of the dredging plant; similarly, the opening up of the mouth of the Danube could not have been carried out as it has if it had not been that Sir Charles Hartley was able to secure, from Messrs. Simons, the dredger the "Percy Sanderson," which was at that time one of the largest bucket dredgers ever built. Following the "Percy Sanderson," still greater dredgers are being made; the last one for the Suez Canal was a great advance, and Mr. Brown has told us of another and still larger one for the Russian Government. This development of dredging plant renders the solution of the problem which faced our forefathers possible at the present time, a problem which was entirely insoluble thirty years ago; and I think the Paper is very interesting from that point of view.

I think you will all unite in thanking Mr. Kühl for his Paper, and in congratulating him on the fact that the Sulina mouth is in a most satisfactory condition, and that in a very short time the second cut will be effected.

Mr. C. H. L. Kühl replied by correspondence as follows :—

En réponse à M. Vander Vin, je dois dire que la coupure entre les milliaires 8 et 18 d'alignement complètement droit, a été draguée à 18 pieds de profondeur réduite à zéro en amont, jusqu'à 19 pieds en aval. Le profil normal est en développement, et les profondeurs sont déjà de 20 à 28 pieds à zéro, à présent.

In reply to Mr. W. H. Hunter, I should say that until the year 1892 there was no limit of speed for steamers in the Sulina branch. As the size of steamers increased, several instances were observed in which full-powered steamers, travelling at full speed, carried away the rubble stone revetments. The regulation for moderating speed was intended for this class. Evidently, if it were found that single steamers of under 800 registered tons damaged the works, the limitation would be extended to them at once.

The class of boats on this river under 800 tons register are of small power and are quite harmless. We find that the violent disturbance of the surface of the water caused by small but fast boats of limited power does not affect the revetments, for want of strength. It is the steamer of large displacement and of full power, going at great speed, which causes a great wave like a bore—following in the wake, along the river banks, and breaking on the revetments with great violence—which does serious damage in this narrow river with its narrow cross-section and limited depth.

[Paper.]

THE RIVER CLYDE AND HARBOUR OF GLASGOW.

By W. M. Alston, Engineer-in-Chief to the Clyde Navigation Trustees.

The transformation of the River Clyde from a shallow stream to a great maritime highway has been so long a favourite subject for writers on the improvement of rivers, that the Author reluctantly enters upon the task of adding another Paper to the already long list; but, on such an occasion as the assembling of an International Engineering Congress in Glasgow, it was felt that the absence of such a Paper would be looked upon as a serious omission. This Paper has, therefore, been drawn up in the hope that, although the subject is familiar to many, there still may be some to whom it will be fresh and interesting. The subject, however, is so wide in its scope that the limits of time and space permit of it being treated only in a general way.

The River.

The actual source of the river is a matter of dispute, the name Clyde not applying all the way. Three head-streams under different names claim the honour of being the continuation of the river, viz., the Clydes Burn, the Powtrail Water, and the Daer Water; but, on an inspection of the map, there can be little doubt that the true continuation is the Daer Water. This determines the main source as being on the north side of the range of hills forming the southern boundary of the county of Lanark, at an elevation of about 2,000 feet above sea-level. For about 10 miles of its course the stream falls rapidly through lonely sheep-grazing country, and thereafter, with many a turn, it meanders through rich pastoral and agricultural districts until the sea is reached. At Lanark, about 53 miles from its source, the well-known falls are found in a rocky gorge about 3¾ miles in length, the total fall in that length being about 230 feet. For the remainder of the distance to Glasgow the fall is gentle, and latterly the stream traverses a portion of those rich mineral districts which have been the source of such wealth and prosperity to the West of Scotland. From its source to Port Glasgow, the river has a length of about 102 miles, and the drainage area of the river and its tributaries may be taken at 1,400 square miles. The principal tributaries connect with the navigable portion of the river, the Kelvin joining at Glasgow, the Cart at Renfrew, and the Leven at Dumbarton.

Omitting towns in the upper reaches, and noting only those which have been at one time, or are still, connected with shipping, these places are, in their order, Rutherglen, Glasgow, Renfrew, Bowling, Dumbarton, Port Glasgow and Greenock. Rutherglen, about 2½ miles above Glasgow, had, in olden times, shipping of its own, and was of so much more importance than

Glasgow that the latter was included in the area over which Rutherglen had power to exact tolls; but nothing was ever done to carry the improvement of the river upwards from Glasgow, and every vestige of the shipping of Rutherglen has long ago disappeared.

The portion of the river which is under the jurisdiction of the Clyde Navigation Trustees extends from Albert Bridge, Glasgow, to Newark Castle, Port Glasgow, a length of about 18½ miles, and their operations within these limits have been carried on under the authority of 23 Acts of Parliament. The navigation and lighting of the estuary, from Newark Castle seaward to the island of Little Cumbrae, are under the care of the Clyde Lighthouses Trustees.

One of the earliest recorded primitive attempts to improve the river was made in 1556 by the citizens of Glasgow, Renfrew and Dumbarton agreeing to work upon the river for six weeks at a time, in order to remove fords and the most prominent sandbanks. As years went on, Glasgow assumed the dominant position on the river and took the lead in all subsequent efforts. In this way the improvement of the river is inseparably bound up with the history of the city of Glasgow.

In 1636, Charles I. granted Glasgow a Charter, in which he refers to the expenditure which had already been made by the citizens in their efforts to improve the channel of the river. This Charter empowered the inhabitants to build ports, and to make the river more navigable between Glasgow and a point now occupied by the Cloch Lighthouse, a distance of 27 miles seaward from Glasgow. It also gave power to exact anchorage and other dues on merchandise and vessels. At this period no vessels of any size could reach Glasgow, and the citizens largely made use of the ports of Troon and Irvine, on the Ayrshire coast, 30 to 34 miles from Glasgow, and between these places and Glasgow goods were carried on pack horses. Despairing of being able to sufficiently improve the river up to Glasgow, the citizens conceived the idea of going down to deep water if it could not be brought up to the city. Accordingly, in 1658, the magistrates endeavoured to secure land at Dumbarton in order to construct a harbour there; but, strange as it may appear, the inhabitants objected to the proposal on the score "that the great influx of mariners and others would raise the price of provisions to the inhabitants." Baffled at this place, and also at Troon, the magistrates turned their attention elsewhere, and in 1668 succeeded in acquiring 13 acres of land beside the village of Newark, on the south bank of the river, about 18 miles below Glasgow. Here they built a harbour, and called the place Port Glasgow.

As the port of Glasgow the town grew, and became of considerable importance. But it is not intended to dwell upon the fortunes of Port Glasgow, and the subject will therefore be dismissed in a few words. In 1772 and 1801 the magistrates secured Acts of Parliament for improving and extending the harbour; and, ultimately, the accommodation consisted of a tidal harbour of about 7 acres water area, with a pier in the centre. In 1831 power was obtained to add a wet dock of about 10 acres in extent, and it was partially constructed. In 1710 the place became the principal Custom House port on the Clyde. Here, in 1762, under the direction of the illustrious James Watt, the first graving dock in Scotland was constructed;

and here, in 1812, was built the famous "Comet," by which the problem of steam navigation in Europe was practically demonstrated. Although in possession of Port Glasgow, the Glasgow magistrates never abandoned the desire to improve the river; and, as their efforts to do so met with success, and shipping was attracted, as it naturally would be, up to the large city, so did the fortunes of Port Glasgow decline, until, by degrees, the interest of the magistrates entirely ceased. By Act of Parliament in 1864, the Harbour Trust was reconstituted, and placed in the hands mainly of local trustees, the representation of Glasgow being reduced to the Lord Provost and the senior Bailie. The Glasgow magistrates are still superiors of the place. Fortunately for the town, it is the seat of a large shipbuilding business; but the harbour is now the picture of neglect and decay.

To return to the Clyde. After the union of Scotland with England in 1707, trade and commerce received a great impetus, and the citizens of Glasgow aspired, more than ever, to have an improved navigation. From time to time the Town Council records reveal the efforts that were put forth, until, in 1755, the magistrates determined to attack the question in earnest. In that year they accordingly consulted the leading engineer of the day, John Smeaton. Smeaton's report is interesting as being the first professional document on record with regard to the improvement of the river. The report dealt with only about 5½ miles of river, viz., the length from Glasgow to Renfrew; and in this reach he found no less than twelve shoals, four of them with only 18 inches depth at low water, and one of them, about 400 yards below the present Glasgow Bridge, with so little as 15 inches depth. Smeaton could not have been very sanguine as to the possibilities of the river, as his recommendation was to build a weir and lock at Marlin Ford, about 4½ miles below Glasgow Bridge, by means of which vessels up to 70 feet in length, and drawing up to 4½ feet of water, might pass to and from the quay at Glasgow. As the result of this report, the magistrates, in 1759, obtained the *first* Act of Parliament for the improvement of the river, the scheme embracing the 12 miles of river extending from Glasgow down to Dumbuck, a point about half-way between Bowling and Dumbarton Castle, where there existed the lowest down ford, with only 2 feet of depth at low water. The then state of the river is very interestingly described in the words of the preamble of the Act, viz., that it is "so very shallow in several parts thereof that boats, lighters, barges, or other vessels, cannot pass to and from the city of Glasgow, except it be in the time of flood, or high water at spring tides."

Fortunately for Glasgow and the river, Smeaton's proposal was not carried out, and, in 1768, the magistrates consulted another notable engineer, John Golborne, of Chester, who gave them better advice. Golborne reported that the river was still "in a state of Nature." He found that it was much too broad for its depth, and his advice was to contract the width by running out jetties from either bank, whereby the strength of the current would be so increased that the channel would be scoured deeper, and, at those places where the bed was too hard for the current to operate upon, he intended that the hard gravel and stones should be removed artificially. By this means, he conceived that the river might be deepened, so as to have 4, or perhaps 5, feet depth up to Glasgow; and he concluded his report by stating that he estimated the cost of the suggested work would be the modest sum of £8,640.

In passing, it may be mentioned that under Golborne's directions a series of levels throughout the river were made by James Watt in 1769.

Following Golborne's report, in 1770, the *second* Act of Parliament was obtained by the magistrates, empowering them to make the river *from Glasgow to Dumbuck Ford* at least 7 *feet deep* at high water of neap tides. The systematic improvement of the river was then commenced by the magistrates, in 1772, entering into a contract with Golborne to deepen Dumbuck ford to 6 feet at low water, and make the channel 300 feet wide, for the sum of £2,300. The actual deepening accomplished by Golborne was 7 feet. In 1781 Golborne revisited the Clyde, and, in his report of that year, stated that it gave him great pleasure and satisfaction to find the general work in such good order and condition, and to observe that the spaces between many of the jetties were filled up and covered with grass, to the great emolument of the proprietors and advantage to the river. At the same time, on sounding at Dumbuck ford, he was gratified to find that since he had deepened it to 7 feet in 1773 it had scoured to a depth of no less than 14 feet at low water. The first survey of the river, on a large scale, was made in 1800 by William Kyle, land surveyor, Glasgow, and an examination of it shows that up to that date 219 jetties had been constructed, and that much land had been reclaimed in the upper reaches of the river, thereby helping to make it, as was subsequently found, too narrow for future requirements.

In 1799, John Rennie, of London, recommended that the ends of the jetties should be connected by low rubble training-walls, the better to guide the currents, and that the materials taken from the river should be deposited behind these walls. In 1806, Thomas Telford found fault with the system of jetties, and urged the completion of the parallel dykes. To show that some considerable improvement had already been effected, Telford mentioned that in the spring of the year the "Harmony," of Liverpool, a vessel of 120 tons burthen, had come up to Glasgow, drawing 8½ feet of water; but he did not say how many tides the vessel probably took on the journey. Amongst other things, he recommended that a towing-path should be formed from Renfrew upwards, a length of about 5¼ miles, so that vessels which might get becalmed by the plantations at Elderslie could be towed by horses to their destination at Glasgow. This towing-path was made in due course, and after its original use ceased, it formed a right of way, which still remains, for a length of about 3½ miles along the river bank. In 1807, John Rennie again reported, and strongly insisted upon getting the river into better train by means of parallel walls or dykes. He then laid down upon the 1800 plan, already referred to, the river lines which he would recommend from Glasgow to about Dumbarton Castle. It is interesting to notice the limited widths which he deemed would be sufficient for the wants of the navigation:—

From Glasgow Bridge to the River Kelvin	135 to 150 feet.
Immediately below the River Kelvin	180 "
Above Marlin Ford	211 "
At Renfrew Ferry	230 "
East of River Cart	240 "
West of River Cart	280 "
At East End of Newshot Isle	294 "
At West End of Newshot Isle...	315 "
At Erskine Ferry	370 "

The *third* Act was obtained in 1809, authorising the magistrates to make the river at least 9 *feet deep* at neap tides *from Glasgow to Dumbarton Castle*, about 13¾ miles seaward of the city. Hitherto, the magistrates and Council had been acting as a municipal Corporation, but by this Act they were constituted statutory *Trustees* for carrying on the affairs of the harbour and river. A small balance of money then due to the Corporation, on account of the navigation, was paid off, and the Trustees entered on their duties, with powers to borrow to the extent of £30,000, on the security of the river and harbour dues. Immediately thereafter, in 1812, with the building of the "Comet," came the introduction of steam navigation, and the dawn of a new era for the Clyde and the world at large.

In 1824, Mr. Whidbey reported, and severely condemned the system of contracting the river, in some cases to about one-third its original width, and shutting out tidal water. It appeared to him that the chief object in the past had been the making of land; that what ought to have been done was simply to pare away points and fill up indents in the shore, so as to allow the tide in large volume to have an easy and uninterrupted flow; and his wish was that it were possible to undo the work of the past. The experience of later years demonstrated that Whidbey was right in his contention; but it must be borne in mind that the Trustees, in the early days of the navigation, were feeling their way and were bound to be guided by the smallness of the trade and the limited means at their disposal.

As yet anything in the nature of dredging had been done with such primitive appliances as harrows and ploughs, and, latterly, by dredgers worked by hand; but in 1824 an enormous impetus was given to such operations by the introduction of the first steam dredger. Reporting in this year, Mr. Clark, superintendent of the river, refers to the improvement effected since 1806, and records that the draught of vessels then engaged in the Liverpool trade had increased to 11 feet; that the great improvement was due to the extension of parallel dykes; and then he goes on to say, possibly with a certain amount of exaggeration, that he could confidently affirm that the new dredging machine had raised more stuff since it was set to work than had been taken out of the river during the preceding twenty years.

In 1825 the *fourth* Act was obtained, authorising the deepening of the river to at least 13 *feet at neap tides from Glasgow seaward to Port Glasgow*, a distance of about 18 miles, thus reaching the present seaward limit of the navigation. In this Act a notable step forward was made, in respect that the magistrates were authorised to nominate and appoint annually five other persons interested in the trade and navigation of the river to co-operate with them as Trustees. This Act also provided for the improvement of a portion of the river above the harbour, in order to permit of vessels loaded with coals passing from the higher parts of the river to the harbour, but those powers were never exercised.

By 1836, Mr. James Walker, of London, was able to report that at the Broomielaw there were 7 to 8 feet at low water; that the lift of a neap tide was 4 feet, and of a spring tide 7 or 8 feet, making 12 feet depth at high water at neap tides and 15 feet at high water of spring tides; and, referring to Smeaton's scheme, he pointed out that the river, which was to be rendered capable of taking craft of about 30 or 40 tons to Glasgow, had, by what

Golborne called "assisting Nature," been rendered capable of floating vessels of nearly ten times the burden.

The *fifth* Act was obtained in 1840, and empowered the deepening of the harbour and river throughout to be carried to at least 17 *feet at neap tides* ; and generally, under these powers, deepening and widening have been going on down to the present day. On the plan relative to this Act, definite lines were laid down for the future improvement of the harbour and of the river as far as Dumbarton. These lines provided for a certain amount of widening in the harbour and upper portion of the river, where width had been lost under the preceding system of contraction ; but, at the same time, they provided for a considerable extent of contraction. In course of years, as traffic grew and vessels increased in dimensions and draught, it is not surprising that the widths thus defined were found, in the upper portion of the river, to be too limited. They have, therefore, been increased where practicable, and efforts are still being made to effect further increases. The Act of 1840 enacted that all land reclaimed from the waterway should become the property of the adjacent landowners. In many cases, therefore, the Trustees have had to buy back from the riparian proprietors, at much cost, areas of ground which had formerly been parts of the waterway, but which had been filled up, partly by the accumulation of material due to the jetty system, and partly by embanking done with dredgings behind the longitudinal connecting walls. Until hopper barges were introduced, the only means of disposing of dredged material was to lay it upon the low ground adjoining the river. Under the Act of 1840, another change took place in the constitution of the Trust, making it a more representative body, and the members came to consist of the Lord Provost, five Bailies, the Dean of Guild, the Deacon Convener, fifteen Town Councillors, the Chairman of the Chamber of Commerce, three members of the Merchants' House, two members of the Trades' House, two persons from the Barony of Gorbals, one person from the Burgh of Calton, and one person from the Burgh of Anderston, or thirty-three members in all.

Subsequent to 1840, eighteen more Acts of Parliament were obtained, making twenty-three in all ; but they applied mostly to harbour and dock works and finance, and it is not necessary to refer to them in detail. In 1858, all preceding Acts were consolidated, and a radical change was effected in the constitution, the Board being reduced to twenty-five members, one being the Lord Provost of Glasgow for the time being, and nine being Town Councillors ; the remaining fifteen being representatives of the shipping, mercantile, and trading interests of Glasgow, viz. :—Two from the Chamber of Commerce, two from the Merchants' House, two from the Trades' House, and nine persons chosen by the shipowners and ratepayers. This constitution remains in force. From the foregoing it will be seen that the makers of the Clyde from 1770 down to 1809 were the magistrates and Town Council of Glasgow, as a municipal body ; that from 1809 to 1840 they continued to act, but as trustees for the management of the river and harbour ; that from 1825 to 1840 they had the assistance of five outside persons interested in the trade and navigation ; and that since 1840 the city representation has been diminished, while the general community has been accorded increased representation.

It is impossible to put the matter in figures; but a large amount of material must have been removed by scour after the inauguration of the system of jetties and training-walls; and scour must have been increased by the introduction of steam navigation, owing to the stirring effect of paddles and screw propellers upon the bottom, and the wash of the surge along the banks. The principal factor in the improvement of the river has undoubtedly been systematic dredging since the year 1824, when dredging by steam-driven machinery was inaugurated. The first steam dredger, set to work in 1824, was of 12 H.P. It dredged to a depth of only 10½ feet, and two years afterwards was altered to work to 13 feet depth. Thereafter, there were added one of 16 H.P. in 1826, one of 16 H.P. in 1830, one of 20 H.P. in 1835, and one of 24 H.P. in 1841. The hulls of the dredgers were of wood. Dredging statistics do not begin before the year 1844; and they show that in the year 1844-45 the dredgers lifted 233,944 cubic yards of material. These old dredgers have disappeared, and their places have been taken by five others, the latest having been added in 1892. This vessel is a single-ladder, twin-screw dredger, 200 feet long by 37 feet broad by 12½ feet deep, with a mean draught of 8 feet. It has 35 buckets, each of a capacity of 22 cubic feet. It is capable of dredging at the rate of 600 tons per hour in 40 feet depth of water, and is able to cut its own flotation into solid ground. The dredger is lighted with electricity.

Up to 1862, all dredgers discharged the material on to wooden punts carrying 8 cubic yards, or 10 tons, and these punts, when loaded, were towed in trains by a steam tug to low-lying lands along the river banks for discharging. In this manner many acres of marshy or useless land were converted into valuable agricultural ground, much to the advantage of the proprietor. Besides depositing on land, in some cases the punts were discharged upon the foreshores of the estuary westward of Dumbarton Castle. The introduction of steam hopper barges in 1862 revolutionised this system of disposal of material, and all dredgers were altered for barge-loading, except one, which was retained specially for working, when needed, in the upper harbour above Glasgow Bridge. From 1862 to 1893, the dredgings carried by hopper barges were deposited in Loch Long, an arm of the sea about 28 miles from Glasgow Bridge, on an area of about 428 acres with a depth of about 35 fathoms, defined by the Admiralty; but, in course of time, objections were taken by the residenters, who alleged that the shores were being polluted; and, in consequence, the Board of Trade prohibited further depositing of harbour and river dredgings after 18th March, 1893, but permitted the continuance of clean material dredged in the making of Prince's Dock, until completion, and authorised a new depositing ground about 46 miles from Glasgow Bridge, at the mouth of the Firth, 3 miles S.S.W. of Garroch Head, in 50 fathoms depth of water. Depositing in Loch Long finally ceased on 31st December, 1897. The total quantity of dredgings deposited in Loch Long between 1862 and the foregoing date amounted to 35,167,329 cubic yards; and the total quantity deposited off Garroch Head between 20th March, 1893, and 30th June, 1900, was 9,971,598 cubic yards.

The dredging plant now consists of five dredging machines, one floating grab, and twenty steam hopper barges, one of them carrying 300 tons, thirteen carrying 400 tons, two carrying 1,000 tons, and four carrying 1,200 tons. The fourteen small barges have single screws, while the six large ones have twin screws. In addition, there are two diving bells for lifting boulders and doing other work, about 180 punts, and one tug steamer for towing punts.

The channel requires vigilant watching, owing to the constant silting going on, due to *débris* coming down the Clyde, and from the Rivers Kelvin, Cart, and Leven. From the streets and sewers of Glasgow alone an enormous amount of deposit is discharged into the river. Fortunately, there is the prospect of release from the latter source in a few years, the Corporation having power to deal with the whole sewage of the city at three precipitation works, one at Glasgow, one near Renfrew, and one at Dalmuir. In the meantime, about one-third of the sewage is treated at the Glasgow station; and it is found that each million gallons produces about 40 tons of sewage sludge per day. At this rate, about 1,500 tons of sludge are daily sent into the river at the present time. During the ten years from 1890 to 1900, there were dredged in the harbour and docks and river 19,296,563 cubic yards, of which 10,576,989 cubic yards were new material, and 8,719,574 cubic yards were judged to be deposit, or an average of 871,957 cubic yards per annum for deposit. Naturally, the greatest amount of deposit takes place in the upper end of the harbour; for instance, immediately below Glasgow Bridge, in the course of a year, silting will range in depth from two to four feet. In further illustration of the possibility of silting, it may be noted as a very extreme case that in a recess or corner at the lower end of the harbour, favourably situated for silting, shoaling for a depth of 13 feet took place between August, 1900, and March, 1901. The dredging and carrying away to sea of this large quantity of deposited material involves a heavy annual expenditure.

From 1844, when dredging statistics commence, down to 30th June, 1900, the total quantity of material dredged from the river, harbour, and docks amounted to 56,591,093 cubic yards; of this, 11,452,166 cubic yards were laid on lands or foreshores, and 45,138,927 cubic yards were deposited at sea. Since 1755, the bed of the river has been lowered at Glasgow, 20 to 29 feet; at the River Kelvin, 29 feet; at Renfrew, 28 feet; at Newshot Isle, 27 feet; at Erskine Ferry, 24 feet; at Dunglass Castle, 29 feet; and at Dumbuck Ford, 27 feet; and the general result is that the bed from Glasgow to Port Glasgow is now practically level. The deepening and widening of the river is still going on, the constantly increasing draught of vessels demanding more depth, and more depth involving greater widths in order that the banks may stand. Dredging is presently being executed to 20 feet below extreme low water, or 22½ feet below average low water of spring tides, corresponding with about 32½ feet at high-water spring tides at Port Glasgow, and 33½ feet at high-water springs at Glasgow; and, with this depth, the bottom widths range from 120 feet at the River Kelvin to 500 feet at Port Glasgow. Out of the 16 miles of channel between the harbour and Port Glasgow, about 10 miles—not continuous—may be said to have attained this depth; while in the remaining 6 miles the depth varies from about 19 feet to 22½ feet below average low-water of spring tides. The progressive deepening of the river and harbour may be seen from the following figures:—

In 1821, the greatest draught of any vessel was 13½ feet; in 1831, 14 feet; in 1841, 17 feet; in 1851, 18 feet; in 1861, 19 feet; in 1871, 21 feet; in 1881, 22 feet; in 1891, 23 feet; and in 1900, 26½ feet.

The greatest obstacles met with in deepening the river have been rock at three places, and deposits of hard clay, with boulders, at several other parts. In two cases the rock was of no importance; but that encountered at Elderslie, a short way above Renfrew, proved a serious obstruction, consisting as it did of a mass of whinstone or trap, extending across the river, and occupying a length of about 925 feet of the channel. This rock was first discovered by the grounding upon it, in 1854, of the "Glasgow," one of the first Transatlantic steamers. Thereafter, various schemes were discussed for its removal, one proposal being to coffer-dam the river and remove the rock by open cutting. The method finally adopted was to bore and blast under water, and then dredge the *débris*. To this end, hand-drilling from a stage and blasting with gunpowder were carried on for a number of years, with the result that the rock was removed to a depth of about 14 feet below low water, for one-half the width of the channel, the depth on the other half being only about 8 feet.

In 1880, the late Mr. Deas decided to effectually complete the work to a depth of 20 feet below low water, by the systematic use of diamond drilling and blasting with dynamite and other explosives. In these latter operations about 16,000 holes were bored, about 76,000 lbs. of explosives used, and about 110,000 tons of whinstone and boulder clay were dredged. The work was completed in 1886, at a cost, from first to last, of about £70,000.

From the River Kelvin down to Erskine Ferry, a distance of about 7 miles, the river presents now the artificial appearance of a canal. Seawards, however, from the ferry, it possesses the estuary form, widening out until, at Port Glasgow, it attains a breadth of nearly two miles. From the Kelvin to Erskine Ferry, sloping dykes, or walls of rough stone, rising to a height of about 3 feet above high-water level, extend along both banks, more or less all the way, the width from cope to cope ranging from 365 feet at the Kelvin to 560 feet at Erskine Ferry. From Erskine Ferry to Dunglass Castle a similar dyke exists on the north side, except where Bowling Harbour intervenes. Between Dunglass Castle and Dumbarton Castle, there is only a half-tide training dyke, about 2 miles in length, on the south side of the channel. This is the oldest dyke on the river, a portion of it having been formed in the latter end of the eighteenth century. Westward of Dumbarton Castle there are no training walls.

The river is lighted by means of two lighthouses, three light-towers, two lighted beacons, one lightship, and seven lighted buoys. For long, the lighthouses and lightship were under care of keepers; but these were dispensed with some years ago, on the adoption of Pintsch's compressed gas for lighting purposes throughout the river. The supply of this gas is procured from the Clyde Lighthouses Trustees, who possess gas-works at Port Glasgow, and also have the necessary steam tender, fitted with gas-tanks, for conveying the gas. The lights burn continuously day and night; and the supply of gas is replenished at intervals of about six weeks. In the estuary portion of the river, in addition to the lighted buoys, which occupy the south side of the channel, ordinary buoys, on the opposite side, help to define the course of vessels. Beacons or perches exist along the banks where needed.

Seaward of the termination of the Clyde Trustees' jurisdiction at Port Glasgow, the channel thence to deep water at west end of Greenock Harbour, a distance of 4 miles, has been much improved by the Clyde Lighthouses Trustees, a channel 23 feet deep at low water having been completed by dredging in the year 1895. The channel has a minimum bottom-width of 300 feet, and has side slopes, varying from 23 to 20 feet in depth, for a minimum width of 100 feet on either side, according to the nature of the material passed through. This channel is also carefully marked by lights on shore, and by ordinary and gas-lit buoys.

While groundings on the journey up or down the river were, not many years ago, regarded as a matter of course, they are now of rare occurrence. Vessels drawing 23 and 24 feet traverse the river almost daily, leaving Glasgow or Greenock from one to two hours before high water, and occupying about two hours on the journey. Steamers of every class of trade, drawing 16 feet and under, pass up and down the river at any state of the tide. All sailing vessels, of any size, are towed by tugs. Even small coasting vessels often club together, and, forming a train, engage a tug to tow them up or down. Large steamers frequently have a tug to assist them ; and the very large ones employ two tugs, one ahead and one astern.

Tides and Weir.

Very little information exists relative to the tidal phenomena of the river during the first half of the period of improvement. It is impossible to say with certainty if any change has taken place in the high-water level at Glasgow; the change in the low-water level has, however, been very striking. In 1755, Smeaton found at Glasgow that springs rose only 1 foot 9 inches, while neaps were just sensible. By 1836, springs had increased to 7 or 8 feet, and neaps to 4 feet. By 1858, springs had increased to 8½ feet, and neaps to 6½ feet ; and at the present time springs rise about 11⅓ feet, and neaps about 9 feet. From this it will be seen that the low-water line has fallen about 9 feet 7 inches since 1755 ; and, strange as it may appear, it is actually lower now at Glasgow than at Port Glasgow.

With regard to the acceleration of the tidal flow, Golborne was the first to observe the interval of time between high water at Port Glasgow and Glasgow; and his report of 1768 gave it as being 2 hours. In 1838, John Scott Russell found it to be 1 hour 23 minutes; and now the interval is taken as being 1 hour. In 1838, Russell also found that spring tides flowed at Glasgow for 4½ hours, and ebbed for nearly 8 hours; now they flow for 5 hours 55 minutes, and ebb for 6 hours 25 minutes.

Like many other rivers, the Clyde has been troubled with a weir. The peculiarity of the Clyde case is that the weir occupied in succession three different sites during a period of possibly over 100 years; it was then removed, but after an interval of twenty years it is in process of restoration. The original site was below the first bridge, built at the Broomielaw in 1772, the duty of the weir being to preserve the foundations of the bridge, which had not been set low enough to suit the subsequent deepening of the river. Here the weir remained till 1842, when it was moved to the lower side of the old bridge at Stockwell Street, where Victoria Bridge now stands; and ten years later it was placed at its third site about 120 yards above Hutchesontown Bridge, now the Albert Bridge. The first two weirs were formed of rough stones; but the third one was a substantial structure of regularly-built masonry between sheet piling. It differed from the other two in also having a lock with double gates for the passage of small vessels; the lock being 74½ feet long by 25 feet wide, with 8 feet depth on the upper sill, and 12 feet on the lower sill, at high water of spring tides. The level of the crest of the weir was about 2 feet below average high water of spring tides; when the river was clear of freshets, the surface level of the water was about 7 feet 11 inches above average low water of springs in the lower harbour, and the water then passing over the crest was about 11 inches in depth. Though the primary purpose of the weir was to preserve the foundations of the lowest down bridge, its ultimate use was to maintain the level of the water in the upper portion of the river, for the benefit of the water-supply works. For many years the presence of the weir was a fruitful source of discussion, some advocating its removal as being a serious obstacle to the tidal flow, while others pleaded that it should remain.

In 1881, the third structure was removed, and, as was expected, large quantities of material were washed down from the bed and banks of the river, all which had, in due course, to be dredged from the harbour at the expense of the Clyde Trustees. Many thousands of pounds were spent by the Corporation and various riparian proprietors in protecting or restoring the banks with sheet piling and pitching; offensive sewage-polluted banks were exposed every tide; and the stretch of river long devoted to boating was much injured for that pastime. In a few years, therefore, the Corporation decided to restore the weir, and to this end secured Parliamentary powers in 1894. Under this Act, the fourth structure, which is a tidal weir of the same type as the one on the Thames at Richmond, has been erected, and the works are now on the eve of completion. Various theories have been propounded as to the effect of the weir on the navigation, one being that it helped to dam up the rising tide in the harbour, thereby permitting a vessel to leave Glasgow so much earlier on the tide. After the inauguration of the new weir, this and other interesting points will be carefully investigated.

Glasgow Harbour.

Glasgow Harbour embraces the portion of the river, about 2½ miles in length, between Albert Bridge and the River Kelvin, with the docks, quays, and other works within these limits; one of the docks entering off the north side, and two off the south side of the river. The harbour is divided into two portions, the upper and lower, the former extending from Albert Bridge to Glasgow Bridge, and the latter from Glasgow Bridge to the River Kelvin.

For many years the small boats or vessels frequenting Glasgow were probably kept moored in the stream, or were beached as close as possible to the river bank; but as traffic increased the want of better accommodation became felt. Accordingly, in 1601, it was found necessary to establish a Custom house; in 1662 the Town Council decided that "there be ane little Key builded at the Broomielaw"; and by 1667 shipping had increased to such an extent that a register of the vessels was ordered to be kept. The next reference to accommodation is contained in an Act procured by the magistrates and Town Council of Glasgow in 1715, which provided for the building of a quay from the Broomielaw to the Ducket Green. Under this Act, the magistrates were to advance such sums as might be judged necessary by the Merchants' House and Trades' House of the city. This work was carried out about 1724. There are no records of the extent of accommodation until the year 1792, when the quayage extended from Glasgow Bridge to Robertson Street, a length of 262 yards. In that year the quay was carried on to York Street, a distance of 120 yards, making the total quayage 382 yards. At the same period the area of the harbour was 4 acres, and the revenue £2,739.

No further increase was made for 22 years, so that the growth of the harbour has practically been confined to the nineteenth century. For comparison, it may here be noted that in the year 1900 the quayage, including harbour and docks, had grown to 15,115 yards, or over 8½ miles, the water area of harbour and docks to 206 acres, and the revenue to £441,419.

In the year 1800, the average width of the portion of river now forming the harbour was only about 150 feet—at present the average is 400 feet; by 1840 less than one-fourth of the length of the harbour had been widened to its present dimensions. To a greater extent than other portions of the river, the formation of the harbour has been the result of long-continued widening and deepening by excavation and dredging. The bed of the river has been lowered, since 1755, from 20 to 29 feet, and since 1824 from 10 to 20 feet. The quays had to keep pace with the growth of the shipping; and for many years it was sufficient to extend the accommodation along the river sides; and this continued so long as ground could be secured. From an early date, however, shipbuilding yards had obtained a footing within the limits of the harbour, until no less than five firms occupied sites on the north side, and four on the south side; and in course of time, to secure further extension of the riverside quays, four shipyards had to be bought up at a heavy expenditure. Five yards still remain within the harbour bounds.

The upper harbour has a quay only on a portion of the north side of the river, 502 yards in length, along which a depth of about 10 feet at low water is maintained; and the use of the harbour is confined to small vessels without masts, or to those whose masts can be lowered to permit of passing through the archways of Glasgow Bridge. The lower harbour has quays on both sides to an unequal extent, of a combined length of 6,284 yards, and they have a depth ranging from about 14 feet near Glasgow Bridge to 18 and 20 feet at low water in the lower portions.

The citizens of Glasgow early evinced a desire to have dock accommodation in place of riverside quays; and so far back as 1806 Telford was engaged to report on the subject, and so did Rennie in the following year. The question continued to be discussed at intervals till, under the 1840 Act, power was obtained to form what is now called Kingston Dock, on the south side of the harbour. The demands of the traffic, however, did not warrant its construction for a number of years; and it was not opened till 1867. This dock has 5⅓ acres of water space, 830 yards of quayage, and a depth of about 10 feet at low water along the face of the quays, and 14 feet at the centre of the dock.

The quays are formed of timber wharfing, with the exception of the entrance, 60 feet in width, which is built with masonry, and is spanned by a single-leafed swing bridge, worked by steam power.

Chiefly with the view that suitable ground might be secured and preserved for dock purposes, power was obtained in 1846 to make a dock on the north side of the harbour, on what is now the site of the Queen's Dock. Towards 1870, the business of the harbour was growing so rapidly that it became necessary in that year to obtain power to extend the quayage on the last-remaining riverside ground on both sides of the harbour, and get fresh authority to make a much larger dock on the north side, now called the Queen's Dock. The dock has a water area of 33¾ acres, 3,334 yards of quays, and 20 feet depth at low water. The entrance, 100 feet wide, is spanned by a single-leafed hydraulic swing bridge. The dock has an outer or canting basin, 1,000 feet long by 695 feet wide, and two inner basins, the one 1,891 feet long by 270 feet wide, and the other 1,668 feet long by 230 feet wide, the pier between them being 195 feet wide. The greater portion of the quays, which are of masonry, are founded on concrete cylinders; but there are portions on piling, on boulder clay, and on rock. This dock was utilised in sections as completed, the final portion being finished in 1880.

In 1883, a still larger dock was authorised, on the south side of the harbour; and seven years later its form was altered. This is what is now called Prince's Dock. Like the Queen's Dock, it was utilised in sections as completed, the first portion being occupied by shipping in 1892, and the last being ready in 1897. This dock has 35 acres of water and 3,737 yards of quays. In arrangement it consists of an outer or canting basin, 1,150 feet in length by a width of from 505 to 676 feet, and three basins, each 200 feet in width and 1,168, 1,461 and 1,528 feet in length respectively. The north basin has a depth of 20 feet, the centre and south basins 25 feet, and in the outer basin the depth varies from 20 to 28 feet, all below low water; the latter depth being given along the west quay, a portion of its length being devoted to the fitting out of vessels of the largest class, and is accordingly provided with a steam crane capable of lifting 130 tons. The quay walls all consist of a substructure of concrete cylinders, with a superstructure of concrete and masonry. The entrance is bell-mouthed in shape, with a minimum width of 156 feet, and is not crossed by a bridge.

Although called "docks" these works are really tidal basins, there being no gates or locks. The question of gates or no gates was carefully discussed many years ago, and the conclusion come to was that tidal basins were preferable on various grounds.

The harbour is provided with three graving docks, all situated side by side on the south side of the river. Two of them enter off the harbour, and the third one off Prince's Dock. The first of these docks was authorised in 1868, and opened in 1875; the second was authorised in 1873, and opened in 1886; and the third was authorised in 1890, and opened in 1898. The leading dimensions of the docks are as follows:—

	No. 1 Dock.		No. 2 Dock.		No. 3 Dock.	
	ft.	in.	ft.	in.	ft.	in.
Length from inside of caisson	551	0	575	0	880	0
Width of entrance at top	72	0	67	0	83	0
Depth of water on sill at high-water springs	22	10	22	10	26	6

The entrance of No. 1 dock is provided with a floating ship-caisson, while the other two have rolling caissons. No. 3 dock has a pair of inside gates, whereby it can be divided, and so form an outer division 460 feet in length, and an inner one of 420 feet.

The safety of Glasgow Harbour in times of commercial depression has been the variety of its traffic, and in this way it comes about that special accommodation has had to be provided for such various trades as river passenger traffic, channel traffic, coasting traffic, coal traffic, ore traffic, the Atlantic steamers, foreign and colonial trades, the timber trade, the cattle trade, and so on. The large shipping companies have berths specially appropriated to them, but the Harbour Master has the option of using them for other vessels when they happen to be vacant. Out of the total length of 15,115 yards of quays, 2,686 yards are devoted to the coal and ore trades, 669 yards to the timber trade, 175 yards to the cattle trade, 7,459 yards to companies having appropriated berths, 630 yards for fitting-out berths at large cranes, and the remaining 3,496 yards are used for general and occasional traders.

Except where open quays are necessary, all the quays are lined with excellent modern sheds. These sheds are generally single-storeyed and 60 feet in width, but at Prince's Dock two-storeyed sheds have been provided, one 1,664 feet long by 70 feet wide, and four of an aggregate length of 5,312 feet by 75 feet wide. The sheds are placed usually 15 or 20 feet back from the face of the quay. The total floor area provided by the single-storeyed sheds amounts to 111,432 square yards, and by the two-storeyed sheds at Prince's Dock 113,292 square yards, together 224,724 square yards, or about 46½ acres. The quays are abundantly supplied with crane appliances. At the fitting-out quays there are six large cranes for handling engines, boilers, and masts for vessels. Two of these cranes can lift 130 tons, one 75 tons, one 60 tons, one 50 tons, and one 40 tons. For coal loading, there are four 19-ton and one 25-ton fixed cranes, and one 25-ton movable crane. In addition to this the Trustees have decided to erect an hydraulic coal hoist at Prince's Dock. For discharging ore there are 29 cranes, ranging in power from 35 cwts. to 5 tons. For general traffic there are 36 cranes, ranging in power from 30 cwts. to 15 tons.

Shipping firms possessing appropriated berths are permitted to supply cranes for their own use, and of these there are three cranes for coaling purposes, and 29 cranes for general cargo use, all movable. In the case of the two-storeyed sheds at Prince's Dock, lowering appliances are provided for transferring cargo from the upper floor to the ground floor, also shoots; the latter, however, are most in favour and generally suffice.

Only at one portion of the harbour does an independent authority come in, viz., at the General Terminus Quay, 431 yards in length, on the south side of the harbour, where the Caledonian Railway, under an agreement entered into between the Clyde Trustees and a former railway company in 1846, have five steam cranes for loading coal, and one small crane for general purposes. The quay was built by the Clyde Trustees, but the cranes and hydraulic capstans were provided by the railway company.

For the supply of water to shipping, the extinction of fires, and other purposes, water mains with hydrants are laid round all the quays. The quays, roadways and sheds are lighted with gas, but in addition electric lighting has been provided for portions of the Queen's Dock and Prince's Dock, also parts of the north and south sides of the harbour.

With regard to railway facilities, the Queen's Dock has independent connection with two companies, the Caledonian Railway and North British Railway; while, on the south side, three companies connect with the harbour quays and with Prince's Dock. By a branch railway, now in course of construction, these companies will in about a year have an additional connection with Prince's Dock.

For the weighing of goods, thirty-one weighing machines are placed round the harbour and docks at convenient points, six of them being suitable for weighing railway waggons as well as carts and lorries, and four machines for railway waggons, etc., two of them being capable of weighing up to ninety tons.

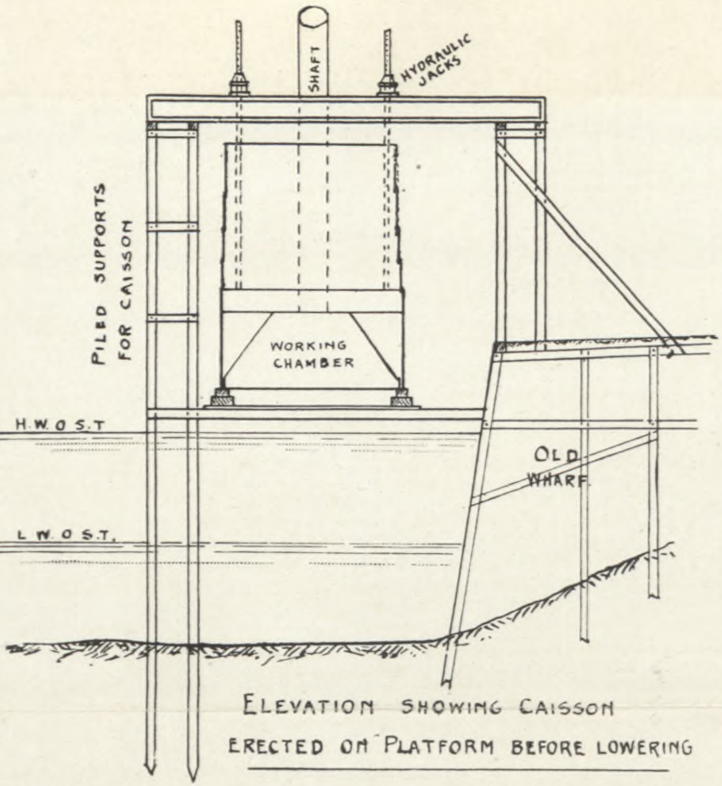
The Trustees have no warehouses in the usual acceptation of the word, nor do they undertake stevedoring business; warehousing is left to private enterprise, and the loading and unloading of vessels is carried on usually by master stevedores, and sometimes by the large shipping firms; in all cases parties require to hold from the Trustees a licence to carry on this business.

The timber trade is accommodated at two places, Yorkhill on the north side of the harbour, with 288 yards of quayage, and fourteen acres of storage ground, and Shieldhall on the south side of the river, where there is a wharf 381 yards in length, and storage ground to the extent of twenty-two acres. As large quantities of sawn timber are brought in by the American liners this material is discharged at the vessel's ordinary berth for early removal, not storage. The cattle trade is also accommodated at Yorkhill, the Clyde Trustees providing 175 yards of quayage, and leasing to the Glasgow Corporation, as the local authority, 23,596 square yards of ground on which they have erected the necessary lairage and other buildings.

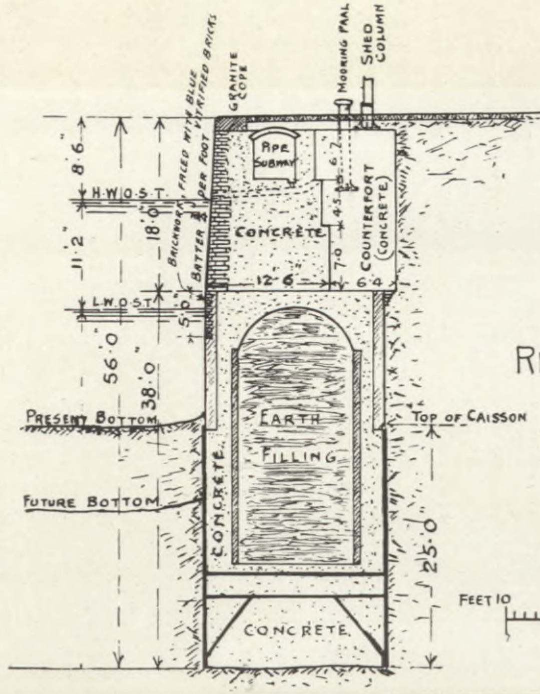
To provide communication across the river below Glasgow Bridge, the Trustees have organised four ferries for passengers and two ferries for vehicular and passenger traffic combined, within the limits of the harbour; while, westward of the harbour, there are two ferries for passengers, one at Govan, and the other at Whiteinch. The cross-ferry traffic is carried on by ten small steamers, with screws at each end, to save turning. These boats are licensed to carry from 93 to 110 passengers, and nine of them are supplied with fire-engines for use in case of fires breaking out on board vessels. One of the vehicular ferries, at Finnieston, about halfway down the harbour, is worked by a boat of novel design, provided with four screws, two at each end, and having an elevated deck capable of being raised or lowered, so as to be kept at the same level as the quay at any state of the tide. This vessel can take 258 passengers and ten carts with horses, or 700 passengers alone. The other vehicular ferry is at Govan, and consists of a boat worked by steam on two chains laid across the river; this boat carries eight horses and carts and 140 passengers, or 500 passengers alone. During last year these cross-ferries carried 8,878,529 passengers and 459,367 vehicles. Westwards of these ferries the river is crossed by two steam vehicular ferries worked on chains, similar to the

Clyde Navigation

Reconstruction of Quay at Broomielaw Glasgow Harbour



Elevation showing Caisson erected on Platform before lowering



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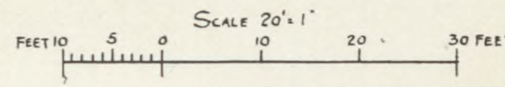
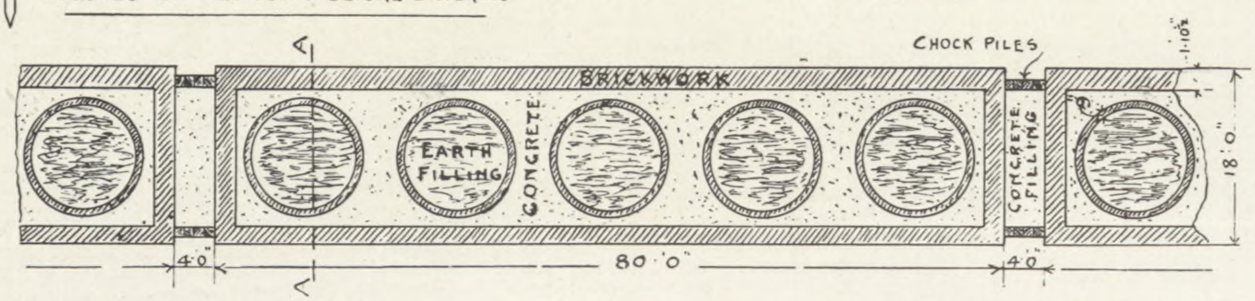


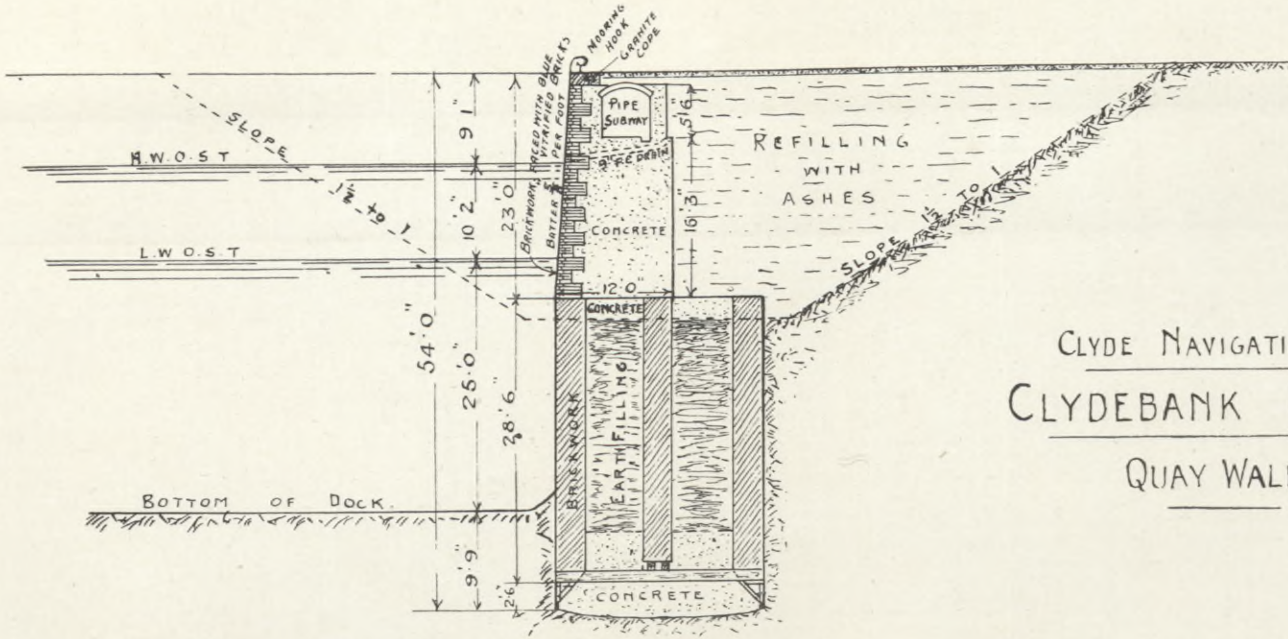


Plan

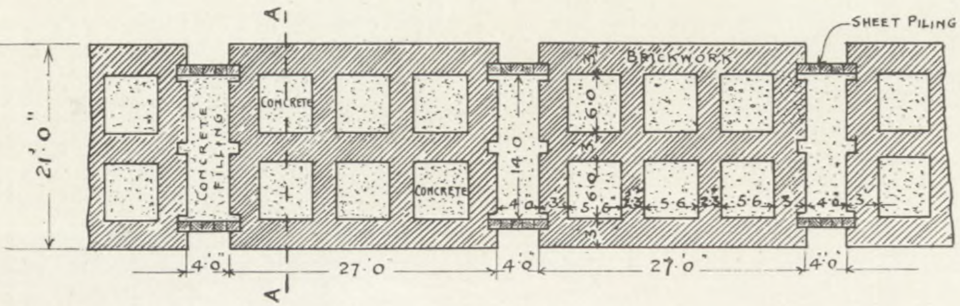
Clyde Navigation

Clydebank Dock

Quay Wall



Section A.A.



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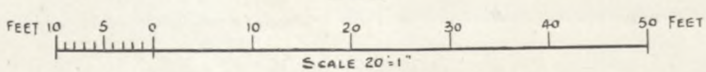


boat at Govan ; one of these is at Renfrew, and belongs to the burgh, while the other is at Erskine, and belongs to the proprietor of that estate.

To provide for up and down river traffic, a service of small steamers was inaugurated by the Clyde Trustees in 1884, to ply between Victoria Bridge, Glasgow, and Whiteinch, a distance of about four and half miles. These steamers, ten in number, have twin screws ; they accommodate from 235 to 360 passengers, and are locally known as "Cluthas," after the Gaelic name for the Clyde. Last year they carried 2,849,263 passengers.

The harbour traffic is still rapidly increasing, so much so that in 1899 the Trustees secured powers to construct a dock on sixty acres of land acquired at Clydebank, more particularly for the accommodation of the coal and mineral trades. This dock is on the north side of the river, about six miles below Glasgow Bridge, and as designed will have 16¾ acres of water and 1,800 yards of quays, with an entrance 200 feet in width.

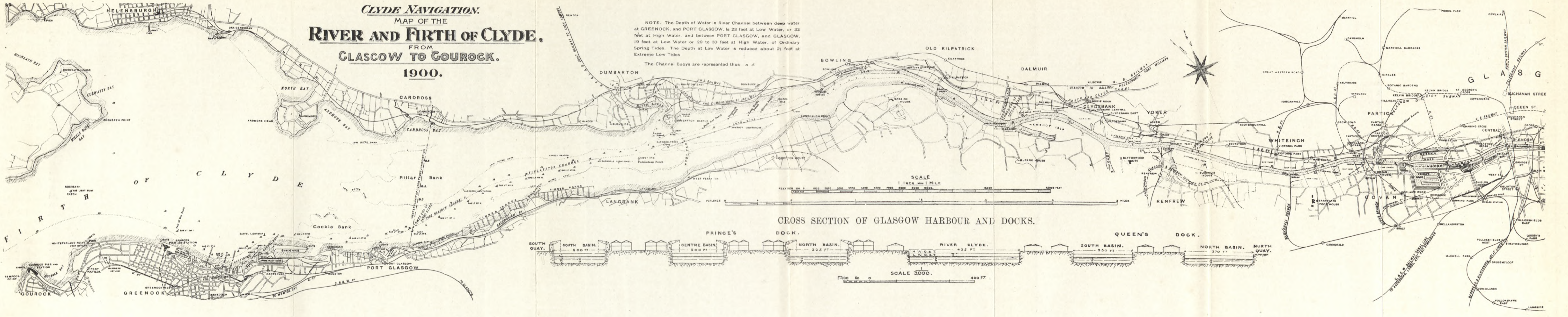
In the same Session, the Royal burgh of Renfrew, on the south side of the river, about 5½ miles below Glasgow Bridge, and having ancient harbour rights, was successful, though strenuously opposed by the Clyde Trustees, in getting powers to construct a dock with about 15 acres of water area and 1,400 yards of quayage. There is a prospect, however, of this scheme now being handed over to the Clyde Trustees. Notwithstanding this additional accommodation in prospect, the Trustees, with wise forethought, have secured and hold for dock purposes about 21 acres of unoccupied land on the north side of the river at Merklands and about 150 acres on the south side at Shieldhall and Shiels.

Space will only permit of a passing reference to the quay walls in the harbour and docks. In the valley of the Clyde a great variety of material is met with ; the strata comprising sand, running sand, gravel, mud, plastic clay, boulder clay, and freestone and whinstone rock. Sand and gravel predominate, and are highly charged with water. As a rule, the bed-rock lies at too low a level to be reached, so that out of the total length of 15,115 yards of quays, not more than about 220 yards have been founded upon-rock, the locality being the north quay of Queen's Dock. From the character of the material, and the fact that all works are tidal and foundations have to be carried to a considerable depth below low-water level, the cost of the walls is high. As the deepening of the river proceeded, the older walls, becoming gradually undermined, were brought down, and required to be renewed, while more modern ones, whenever practicable, have had to be strengthened at much cost with sheet piling driven in front and tie rods taken back to blocks of masonry. For the last thirty years cylinder foundations have been largely used ; the cylinders firstly being made of brickwork, but subsequently of concrete. At the present time two walls of novel design are in course of construction, the one at the Broomielaw, Glasgow, and the other at the new dock at Clydebank. At a part of the Broomielaw there is a particularly bad deposit of muddy clay, in which one wall and two wharves had failed to stand, and the method of construction now adopted, it is hoped, will prove effectual. The work consists of a substructure of caissons, each 80 feet long by 18 feet broad, separated from each other by a space from 2 to 3 feet in width, made good by piles and concrete after the caissons are sunk ; and on the substructure so obtained a superstructure of concrete and brickwork is erected. The caissons are sunk through the clay to depths ranging from 54 to 70 feet. They are built of steel for the first 25 feet in height, after which the further height required is carried up in brickwork and concrete, this amount of building being so adjusted that when the caisson has been sunk to its intended depth, the top of the building will have been brought to the level of 2 feet above low water. The sinking of the caissons is done by men working in the bottom under compressed air. The wall at Clydebank Dock, like the foregoing, consists of a caisson substructure and a brick and concrete superstructure. The caissons, however, are different. They are 27 feet long by 21 feet broad by 31 feet in height, and are built of brickwork *in situ* on a steel shoe 2½ feet in depth, set on the floor of a trench cut to a level of about 6 feet below low water. In this case the caissons are being sunk to a depth of 54 feet below coping level of the quay by a grab digger operated by a steam crane.

As stated in the opening pages of this Paper, the city and the navigation have gone forward hand in hand. Commencing the work of improvement with a population of only about 40,000, the city has steadily grown in numbers and in wealth until it now holds rank as second in the United Kingdom, with a population of 760,406. As regards the navigation, the harbour accommodation, which about 1792 could boast of only 2½ acres of water and 262 yards of quayage, has now been increased to 206 acres of water, including docks, and over 8½ miles of quays. The river, which was navigated only by the smallest of vessels and boats, now bears on its bosom the largest steamers sailing to the ends of the earth; while into its waters are launched almost daily the noblest triumphs of mercantile marine and naval architecture.

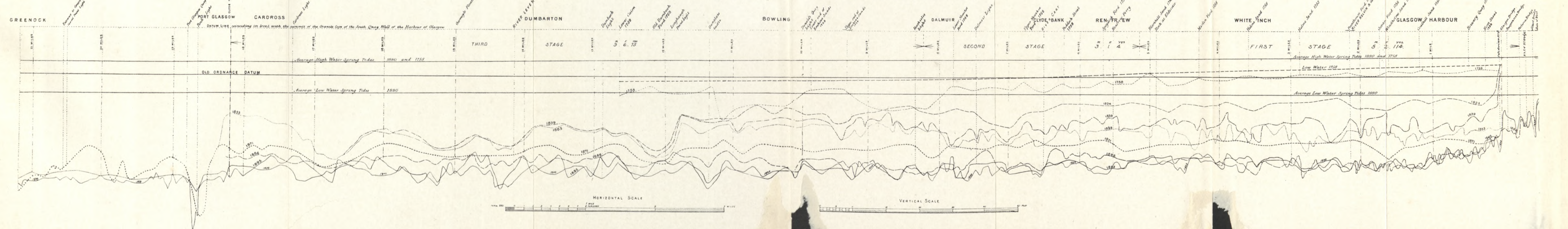
The revenue from the river and harbour, which in 1770 was only £147, last year reached the large sum of £441,419. The shipping registered at the port of Glasgow, numbering in 1810 only 24 sailing vessels, with a tonnage of 1,956 tons, last year had increased to 1,605 sailing and steam vessels, with a tonnage of 1,582,229 tons. The Customs revenue collected at Glasgow, which amounted to only £125 in 1796, last year attained the enormous sum of £1,952,910. To show the volume of business now reached, the total number of vessels arriving at Glasgow last year was 15,899, with a tonnage of 4,361,597 tons; while the tonnage of goods imported and exported was 7,215,368 tons.

The transformation of the river has not been effected without large financial outlay. Since 1810, when the management of the river and harbour was placed under trustees, down to June, 1900, the capital expenditure has been £7,430,702. Of this there was borrowed from the public £5,790,187, and of the balance of £1,640,515, nearly 1½ million has been provided out of surplus revenue, the surplus last year being £42,237. In conclusion, the improvement of the River Clyde is a magnificent example of what can be accomplished by a municipal body and a Corporation, unassisted in the slightest degree by Government aid; and too much praise cannot be accorded to the long roll of men who, by voluntary service, have been the means of bringing the navigation to the proud position which it now occupies.



Longitudinal Section of the River Clyde

Showing greatest depths of the channel in the years 1758, 1824, 1839, 1853, 1871, 1886, and Section taken on Centre Line of Channel in years 1895, and 1899.



DISCUSSION.

Mr. R. C. H. Davidson: I should like to ask the Author of this very interesting Paper what the effect of changing the dumping ground from Loch Long to the sea had upon the quantity of dredging, and also upon the cost; because it seems to me rather a case of sentiment *versus* utility.

Mr. William Brodie: As regards the dredging, I should like to know the speed of the hopper barges now employed, how long the round journey takes, and the depth of water in which the dumping is now done. As regards the newest form of dock construction, perhaps Mr. Alston would inform us to what depth the concrete goes down in the space between the caissons? Does it go down to the depth of the caisson on each side of it, or not? I think I am right in saying that there are no great tidal variations in the level of the water on the Clyde, and it is not necessary to impound the water in the docks, so that the question of preventing the flow of water between dock and river is not important; but the depth of the foundations throughout may be a matter of interest.

Mr. Alexander Gibb: With regard to the sinking of this new monolith, I should like to know whether the brickwork in the cross walls is put in at the same time as the brickwork on the outside walls, or if it is put in afterwards; and whether, in the latter case, it has been found necessary to timber the inside during the process of sinking. I had some experience of concrete monoliths of a somewhat similar shape to the one shown in the diagram, and of the same dimensions, but 3 feet longer; and we found it necessary to timber the whole of the inside of the monolith while it was going down, thus adding greatly to the expense.

Mr. H. Home: Is it not difficult to keep the caissons in line, seeing that they are so near the old work? I suppose the caissons have girders over the roof of the working chamber, and also girders at higher levels to stiffen them, and that there will not be any timber stiffening in the caissons.

Mr. W. H. Hunter: One of the most interesting questions raised by the Paper, and upon which discussion appears to be directly challenged by the Author, is as to the policy of the Clyde Trustees, and of their different engineering advisers, in constructing tidal basins instead of docks proper. The Author has told us that the rise at spring tides now is something like 11 feet 4 inches, and therefore there must be a range to that extent in these large docks at spring tides, with steamers of increasing size lying at their quays. One would imagine also that the absence of lock gates, or entrance gates, as the case may be, would lead to a considerable increase in the silting of the docks; that the docks would be little better than cesspools, places of deposit in still water, in which an enormous amount of silt would accumulate. Having regard to the almost universal experience in this country of the necessity of keeping steamers, that may run up to from 12,000 to 16,000 tons dead-weight capacity, as nearly as possible on the same level while loading and discharging, one would be glad if the Author could tell us what the reasons were that led to the conclusions that tidal basins were preferable. He states that there were various grounds for that conclusion; and I am sure it would be interesting and instructive to us if he would tell us what the grounds were which led to the conclusion to abandon the construction of gates of any kind, and in that respect to make the Clyde almost unique.

Mr. JAMES BRAND: With regard to the sinking of monoliths, I should like to ask what was the object in dividing the area into so many spaces? It seems to me, in the diagram, that these spaces are 3 feet 6 inches lengthwise, and about 4 feet the other way; if so, what is the object of having so much brickwork, instead of having larger openings? I understand the material is small sand and gravel; and I should like to know whether there is any blowing, or whether the water is taken out in order to get the cylinders to sink, and whether the cylinders are loaded in sinking them through the material.

Mr. R. GORDON NICOL: It gives me great pleasure indeed to offer my congratulations to Mr. Alston for the excellent Paper he has given us to-day on one of the most important features of the Congress in Glasgow. There is no Scotchman who is not stirred to his inmost core at the great achievements which have been made on the Clyde, which have made the name of a Scotchman respected, not only in Great Britain, but also throughout the whole of the commercial world. With regard to the river itself, the work done on the Clyde may be almost termed a canalisation of the river, because the stream which used to meander towards the Forth of Clyde at one time could hardly be designated by the term "river," certainly not in the sense of a navigable river. It reflects great credit on the citizens of Glasgow that they have been able to transform that very shallow river into such a magnificent waterway. Almost all undertakings of such a nature, from their initiation, have been found afterwards to exhibit a great want of foresight; and it might be said that the people of Glasgow have been very shortsighted in allowing so much of the ground to pass out of their hands in the vicinity of the harbour—ground that had to be acquired afterwards at a very great cost. In an undertaking with which I have the honour to be connected, we are at present engaged in acquiring land all round the harbour for extension purposes—land which could have been obtained thirty years ago for about £200 an acre, and a considerable portion of which we have acquired for £7,300 an acre; therefore we can appreciate the want of foresight in carrying on undertakings like this. Those engaged in the earlier stages had no conception of the magnitude which these undertakings would afterwards assume.

One feature alluded to in the Paper, but not yet referred to in the discussion, is the system of two-storeyed sheds which have been adopted at Prince's Dock. These sheds, the Author will say, are the outcome of the very limited quay space which is available for the discharging of vessels; I understand that the sheds in Glasgow are about 75 feet wide. A very common and useful width for a single-storeyed shed would be about 150 feet—that is, for the discharging of very large vessels occupying berths opposite the sheds; I take it that the 75 feet adopted gives the ultimate width of about 150 feet. In Aberdeen I have adopted this system of two-storeyed sheds, following the example of those in Glasgow, simply because we are very much limited in our quay space. I find that the upper storey is very much more valuable than the ground floor; for in a ground floor you have to allow a great amount of carting space, but in a top storey, as a rule, you can fill it up solid. When you hoist your goods from the ship, you practically hoist them to the height of the upper storey, land them on the balcony, and save all the time of lowering them on the quay, and then lifting the empty hoist. With regard to loading goods into waggons or carts to take them away, you have the advantage of only having to shoot them down into the various vehicles; and I reckon that with us the two-storeyed shed is equivalent to three single-storeyed sheds. I noticed yesterday, on visiting the hydraulic cranes which are being fitted in front of those sheds, that a considerable amount of space might be saved between the sheds and the ships. In Aberdeen we have placed sheds much nearer the quay, and placed the cranes on the roof of the sheds, in a similar way to that adopted at Liverpool; in our case, however, we have introduced electric cranes.

With regard to the quay walls themselves, I think the method of sinking the caissons is an admirable one, and certainly allows one to go to a very great depth, without the expense of coffer-dams and taking out the foundations. I always think we lose a great deal of bearing power on the front of the quay wall by having the rounded edges projecting forward. The system we are carrying out in Aberdeen is to have the quay walls rectangular, and all faced with granite. I will not advertise Aberdeen granite; but I really think all work of this nature ought to be faced with some hard stone, as the amount of wear and tear that goes on on the face of the quays necessitates a very hard surface. The walls which are being put down in the interior of our dock at Aberdeen are placed at such a depth that it will enable us to remove our dock gates altogether, with a rise and fall of about 13 feet. At present it is a very great inconvenience that the coasting trade cannot be accommodated during all states of the tide; and it is our intention, in doing all our work inside, to put our berths down sufficiently to load our ships at all states of the tide.

Mr. Vernon-Harcourt: With regard to the Clyde, it has somewhat special natural conditions in opening into a sheltered estuary, instead of like the Tyne and the Tees, which require to have breakwaters erected at their mouths in order to protect them; and that is a special feature which has to be taken into consideration. In the Clyde you have a perfectly protected entrance, free from drift, which has been of great advantage to the river; but of course the Clyde has been entirely transformed by the dredging which has been carried on for so very many years.

With regard to the wells that have been sunk, it is rather a pity that, as the discussion has partly turned upon these various forms of sinking the foundations, we do not find these diagrams in the Paper itself. I think it would be a great advantage if Mr. Alston could give us reductions of some of those diagrams exhibited on the walls; and I would certainly try to get them incorporated with his Paper in the volume of our Proceedings.* I am

* These additional Plates will be found opposite p. 112.

sure these drawings would be a valuable addition to the Paper, because it would be impossible quite to understand this discussion without having the drawings, which are very interesting in themselves, so as to show what the discussion turns upon. With regard to the wells themselves, we have the ordinary small round wells at first, then afterwards in groups of three, and then, later on, what Mr. Alston terms a monolith of brickwork, but which I should hardly designate by that term, because inside there are hollows which appear to be filled up with concrete. I saw, many years ago, when my friend Baron Quinette de Rochemont was the engineer at Havre, masonry wells that were being sunk on the alluvial foreshore of the Seine estuary for the walls of the Bellot dock. It seemed to me a better system on the whole for sinking these foundations for dock walls, having merely a square single well, instead of a variety of hollows which have to be filled up. I should have imagined it was more convenient for sinking these foundations to have had a single capacious hollow than several small ones.

With regard to the other system that has been adopted—that of compressed air—it is very good. I recollect seeing that system in a somewhat similar case at Rotterdam, where they sank foundations for quay walls in the alluvial bed of the Maas to a moderate depth. In sinking foundations by compressed air, you can tell exactly what your foundation is, and you can carry down your foundations to any depth that is required, and in that manner make certain that you have a perfectly stable wall. It is an excellent system, but in many cases rather more expensive.

Mr. Hunter has raised a most interesting question. He objects to the open basins that are adopted on the Clyde. It is obviously, however, a great advantage to have these open basins, if you have not too much rise of tide, because you do away with all the difficulties, delays, and cost of locks, and gain the space that the locks take up; and you do away with gates and their machinery; and access to basins is much more convenient. As regards the Clyde being quite unique, I do not know that I quite follow Mr. Hunter in that respect, because there is Southampton, which certainly has a rise of tide somewhat like the Clyde; and there they have, with one exception—which is an old dock—deep-water quays, which give you about 30 feet of water at low water, which are approached at any state of the tide, and which are perfectly open. Then again at Antwerp they have a peculiar system. They have docks there closed by gates; but they have also river quays along the Scheldt, where there is a greater rise of tide than in the Clyde, where they carry on a very large traffic, and where the vessels have to rise and fall with the tide.

Mr. W. H. Hunter: They are small coasters, not large vessels.

Mr. Vernon-Harcourt: No, they are large steamers. The quays are constructed by the Government; and the docks have been built by the Municipality of the town. They are extending the quays a good deal; and they regulate the river at the same time that they build the quay walls; these have been founded in every case by means of compressed air. They float out the caissons into place, weight them by building the quay walls on the roof of the working chamber, and then sink the caissons to a firm foundation; and I saw them carrying out that system twenty years ago. In a similar way, Rouen is entirely provided with quay walls and open basins along the Seine.

With regard to the question of the weir on the Clyde above Glasgow, I should like to ask the Author in what way the weir is worked. The one which he says is exactly the same as at Richmond is what we may call a half-tide weir: that is to say, the water is kept up at half tide, to cover the mud-banks that formerly emerged at low water above Richmond; and the other half of the tide is allowed to flow up and down without obstruction. I suppose this weir on the Clyde is somewhat for the same object; and for that kind of purpose, where gates have to be opened and closed at almost every tide, except in the night-time, when they let the tide flow in and out at will, it is a great advantage to employ Mr. Stoney's free rollers and counterbalance weights, for the purpose of raising and lowering the gates very rapidly and easily. If the Author could tell us how quickly those gates are opened and closed, and at what state of the tide it is proposed to close them, so as to maintain the water-level above, it would be interesting. I could hardly agree with the view expressed as to the value of the weir in damming up the rising tide in the harbour; that is hardly a result that would very much help navigation. It is, however, certain that if you have an unobstructed tide-way, the tide would rise to its full height without requiring a weir to dam up the water. I should be as much as possible against having any obstructions to the flow of the tide up the river; but of course there may be some local reasons, such as the boating above the weir, and the injury to the banks, for having this particular weir. A weir, however, checking the upward flow of a tidal river charged with silt, is certain to promote deposit below the weir.

One has always heard that the dredging on the Clyde has been carried very far beyond its natural power of maintenance by the current of the river; and I should like to ask what proportion the actual dredging for the maintenance of the depth bears to the amount of dredging that is carried out. I presume the Clyde is to a small extent being deepened, although the ground-line on the longitudinal section seems to show it is mostly a question of maintenance now, rather than dredging for deepening. But if deepening is still being carried on, I should like to ask what proportion the maintenance of the depth bears to the total amount dredged every year. Dredging for maintenance was a large amount in former years; and I suppose it tends to increase rather than diminish. I am sure we are very much indebted to Mr. Alston for his valuable Paper on one of the most interesting and successful river works in Great Britain, and for the ample diagrams with which he has elucidated the subject.

Mr. W. M. Alston: With regard to dredging, depositing on land was so very expensive that carrying out to sea was adopted for the purpose of saving cost. We considered the objection to depositing in Loch Long was very sentimental indeed, and we held that the people themselves did far more harm than we did. No diminution in the depth of water was discoverable, notwithstanding careful soundings made by ourselves and the Government authorities, and nothing could be found of an objectionable nature; but sentiment prevailed, and we were driven to another site. The result of going so far away was that larger barges had to be constructed to contend with the rougher weather; and we really find that, although the stuff is carried further, it is being carried rather more cheaply than it was before, owing to the fact that the larger barges carry a greater bulk. Mr. Brodie asked some questions regarding the Clydebank caissons or monoliths. The space between the monoliths is purposely kept as shown on the cartoon, to permit of a digger getting in between the caissons after they are sunk, and excavating the space, which is ultimately filled up with concrete; but before that operation takes place, piling is driven, the piling going down to the top of the shoe.

Mr. WILLIAM BRODIE : Does the concrete go down as far as the pile?

Mr. W. M. ALSTON : The concrete goes down as nearly as possible to the bottom of the pile. Mr. Brand also asked some questions with regard to the monoliths. He seemed to be inclined to favour the making of the spaces larger; but the view taken was that the holes should be only of such size as would be sufficient for a digger to work in, and that the more brickwork that could be put on the better, in order to give weight to the caissons. So far this idea has proved correct, because weights are being used in the sinking of these caissons; the sinking being done simply by a grab worked by a derrick crane. The grab is free to operate in any one of the holes; and if there is the slightest tendency in the caisson to go off the level, the grab is directed into the hole necessary to counteract that. The water in the wells is not taken out, and the caissons are sunk without blowing; but the caisson becomes filled with water in a short time, and the grab works through the water. To carry the cross-walls, rolled joists were first used; but to reduce the expense timber was adopted. In a short time after the brickwork has set, there is practically no weight upon the timber. The shoe is set up in the trench near low-water level, and one-half of the height of the monolith is built *in situ*. Digging is then commenced, and is carried on so far; and then the remainder of the height of caisson is built, and digging resumed; and the caisson is put down to its intended depth.

With regard to Mr. Home's question, the working chamber in the caisson being sunk at the Broomielaw is shown on the cartoon by the white space at the bottom of the caisson; and immediately above that is a strong system of girders. Above that again there is open bracing; some few timbers are put in temporarily; but in a short time building in the form shown on the plan takes the place of the timbering. The steel-work itself extends to only 25 feet in height; and any height above that is built in brickwork and concrete. Mr. Nicol referred to the facing of the quay wall, and suggested granite. We have used freestone to a very large extent, and latterly moulded concrete blocks laid in the same manner as freestone blocks; but the latest practice is to face the walls with vitrified blue bricks. Mr. Nicol referred also to the possible want of foresight of the Clyde Trustees. They have been very much handicapped, no doubt; but it was exceedingly difficult for them to see in past years how things were going to develop. It was unfortunate that, when new river lines were adopted, and dykes built, the land which was reclaimed from the river did not remain in the possession of the Clyde Trustees, as it originally did, from high-water mark to high-water mark; but the land from high-water mark to the dykes fell to the riparian proprietors, and in many cases the Clyde Trustees have had to buy back this land. Mr. Nicol also referred to the two-storeyed sheds; one is 70 feet, and the other four are 75 feet wide. We should perhaps have made the sheds in single storey if we had had width of ground ; but our docks are all within the city limits, and it can therefore be well understood how valuable was the ground, and that it was not possible to obtain very liberal widths for land and water space. A certain amount of railway work is carried out at the docks, although the traffic is chiefly undertaken by cartage ; and it was thought necessary to provide two lines of rails between the coping and sheds, and that is the reason why the space is 20 feet wide, instead of the narrow width suggested by Mr. Nicol.

With regard to the weir, I may explain that it is not a Clyde Navigation work, but is being constructed by the Corporation of Glasgow. The original reason why a weir was constructed on the Clyde at all was to preserve the foundations of the lowest down bridge, which it did for many years ; and then another reason arose. The level of the water had to be maintained in connection with the waterworks ; and various Acts of Parliament prevented the Trustees on any account removing the weir until another water supply was introduced. The weir, from first to last, probably existed for a hundred years, but occupied three different sites. In 1881 it was done away with ; and in a short time very injurious results followed. The river banks fell in, the Corporation and proprietors were put to very great expense in protecting the banks, and at low water the foreshores became extremely offensive, owing to the areas of mud which became exposed. The Corporation decided, therefore, to restore the weir, but in a different form. A short time before arriving at this decision, the tidal weir had been constructed at Richmond ; and it was resolved to adopt the same system. The gates, I understand, are to be raised at every tide, so that the river may have for a time a free scouring effect ; then when the gates are lowered the water-level will be maintained. Mr. Vernon-Harcourt referred to the possible raising of the level of the water by the presence of the weir. I may explain, in that connection, that there were a good many opponents to the removal of the weir ; and that was one of the points they brought forward. They said that so long as the weir was there, the rising tide dammed up against the obstruction, and allowed a ship to get away sooner on the tide than if the waters had been free to expand into the upper reaches of the river. This question will be carefully looked into after the weir is completed, which will be in a few months' time.

Mr. VERNON-HARCOURT : At what height will the weir keep up the river above it ?

Mr. W. M. ALSTON : About high-water level, or very near it.

Mr. Hunter referred to tidal docks. The Clyde Trustees were authorised to construct two docks ; and, following the ordinary custom, they were to be docks with gates. The works, however, were not proceeded with for a number of years ; and by that time the question was raised whether or not gates should be adopted. Ultimately the decision was reached that it was of more importance to allow vessels liberty to come and go at any state of the tide, than to keep them impounded in a dock whose gates would be opened only about the time of high water. You are aware how foul is the water of the Clyde ; and it was felt that a serious nuisance would have been brought about by large bodies of impounded water. As it is, the water is changed or circulated more or less at every tide. The question of keeping large steamers afloat is an important matter ; but, as you know, very large steamers trade on the Clyde, and there is really not much objection raised by them at all, if any.

Mr. W. H. Hunter : Do these large steamers take the ground ?

Mr. W. M. Alston : They take the ground sometimes.

Mr. W. H. Hunter : Do the Anchor Line or the Clan Line boats take the ground ?

Mr. W. M. Alston : Yes, all the liners—the Smith Line, Clan Line, Anchor Line ; all these vessels are on the same basis.

Mr. W. H. Hunter : They actually take the ground ?

Mr. W. M. Alston : Yes.

Mr. W. H. Hunter : I am very much obliged to you for that information. I know that, in the Ship Canal, if they only touched the ground there would be a very serious disturbance.

Mr. W. M. Alston : There is just one other point which was raised by Mr. Vernon-Harcourt ; he asked what was the proportion in dredging between new work and maintenance. I may say that last year the proportion was about half and half ; and in my Paper (p. 105) the result is given for ten years, showing that 8,719,574 cubic yards were judged to be deposit, or an average of 871,957 cubic yards per annum. During the ten years from 1890 to 1900, there were dredged in the harbour and docks and river 19¼ million cubic yards, of which 10½ million cubic yards were new material and 8¾ millions deposit. The latest information is that the quantities for last year were just about half and half. A very large amount of deposit comes in from the city of Glasgow ; and you will find it stated on the page referred to above that about 1,500 tons of sludge are sent into the river daily at the present time.

The Chairman : I am sure you will all admit this has been a very interesting Paper, and a very valuable record for future reference. The case of the Clyde always reminds me of the gentleman who stated that an example of the beneficence of Nature was that Providence had made great rivers run by the side of great cities. That was not done by Providence in the case of Glasgow ; but it has been done by the dogged perseverance of its inhabitants. A friend of mine, who lived thirteen miles below Glasgow, told me he remembered riding across the Clyde near Bowling on his horse, and fording the river with a depth of perhaps 1½ feet of water. Now we see the largest ocean-going ships passing this identical spot.

With regard to the caisson and cylinder foundations, we, like so many other people, have had to learn from the East. The well foundation is older than any civilisation in this country ; and we are now using the same kind of foundations that were used by the inhabitants of Hindustan for many thousand years. That description of foundation work is particularly suitable for many kinds of ground. I have employed similar caissons a great deal myself. In very many cases they have been extremely useful ; and in other cases they have given rise to difficulties, where hard and impermeable strata are encountered between the various layers of sand. It is a very interesting question to note, under the conditions of modern machinery for pumping excavated material, to what distance it pays to adopt transport to the sea, as compared with pumping on to the land. It is quite an open question whether the time has not now arrived when the dredgings of Glasgow might not be pumped on to the foreshores below Erskine as cheaply as they are conveyed 46 miles by sea, taking into account, not only the length of the journey, but the interruption and delays due to bad weather. No doubt, when the change was made, it was a wise one on the score of economy; but it is at least debatable now whether it would not be advantageous to avoid going so far to sea.

Mr. Alston says, in the very interesting discussion on the tides, that it is impossible to say with certainty if any change has taken place in the high-water level at Glasgow, but that the change in the low-water level is very striking. Some years ago, the late engineer, Mr. Deas, considered that it had been proved there had been a rising of the high-water level; I know afterwards he expressed some doubts on the subject; but up to a certain date he was of opinion that the high-water level had been raised by these great works of improving the hydraulic mean depth, and the consequent acceleration of the tidal wave. *A priori*, it seems to me a thing that is in itself more than probable that if you increase the hydraulic mean depth of a river, and very greatly accelerate the tidal wave—in this case I think by something like 50 per cent.—between the open sea and Glasgow, and if we have at Glasgow a weir preventing the energy of the tidal wave being dissipated further up the river, I say it seems more than reasonable—in fact, almost necessary—that the level of high water must be raised in order to destroy the momentum of the tidal wave. Of course that need not be the case where there is plenty of room for the momentum to be destroyed by the tide flowing further up the river. But in the case of a weir or obstacle being placed across the river, where the hydraulic mean depth is increased and the tidal wave is accelerated, I cannot see how the momentum of the tidal wave is destroyed, except by raising the plane of high water. The raising of the plane may not be very serious, yet I think it is necessary that it must be raised.

I have to thank Mr. Alston for the very interesting Paper he has put before us; and perhaps you will allow me to conclude my remarks to-day by quoting the motto we saw on the banner last night in the municipal building —"Let Glasgow flourish."

(*The Meeting was then adjourned.*)

PROCEEDINGS OF SEPTEMBER 5.

Sir JOHN WOLFE BARRY, K.C.B., LL.D., F.R.S., in the Chair.

[Paper.]

IMPROVEMENT WORKS ON THE CLYDE ESTUARY.

By D. and C. STEVENSON, B.Sc., F.R.S.E., M.M.Inst.C.E.

THE lower estuary of the Clyde, which may be called the key to the Upper Navigation, and with which this paper deals, is under the jurisdiction of the Clyde Lighthouses Trustees, the jurisdiction of the Clyde Navigation Trust ending above Port Glasgow. The estuary extends from Port Glasgow westwards, the channelway passing through sandbanks until the "tail of the bank" is reached, below which the estuary is more of the nature of a firth or fiord, the depth of water varying from 180 feet at Cloch to 370 at the Cumbrae, although it is deeper at some places, such as opposite the Cloch, than at places more seaward, such as Skelmorlie. It is encumbered by several "patches," the highest up being that of Roseneath, with a depth of 7 feet over it at low water, situated midway between Fort Matilda and the Roseneath shore. The depth of the estuary here varies from 60 to 220 feet; and the slope of the bottom from the tail of the bank is no less than 190 feet in one mile. The Gareloch, one of the numerous arms of the Clyde estuary, branches off here; and a little lower down, where the estuary takes a right-angled bend to the south, Loch Long comes in, which is navigable for large ships to its head, which forms the starting-point of the projected great Scottish canal connecting the Clyde and the Forth by Loch Lomond, which, being only 10 feet above high water, necessitates little lockage and has an almost inexhaustible supply of water. From Loch Long the Clyde estuary is practically the sea, with but few dangers. The Gantock, lying off Dunoon, is guarded by a gas-lighted beacon; then another obstruction, called the Warden Bank, is met with, which till recently was not shown on the Admiralty charts, and was not generally known to exist. It forms an extension of Lunderston Bank, and has 34 feet of water over it at dead low water, so that it does not form a danger to ordinary traffic of the present draught. Within a few yards of this rocky ledge there is a depth of no less than 300 feet, so that the west side of the Warden Bank is a submarine precipice. Skelmorlie Patch is the next shoal, the boulders coming to within a few feet of the surface. It forms a danger at present guarded by a gas-lighted buoy and bell. The estuary south of this to the Little Cumbrae is from 30 to 60 fathoms in depth, through which the navigation is unimpeded by dangerous shoals.

The Clyde, it will be seen, differs from most of the navigable rivers of this country in that it does not flow direct into the sea with the natural accompaniment of a bar, but enters into a deep and sheltered estuary. The estuary itself is encumbered with sandbanks, but owing to their sheltered situation they are not stirred up to any great extent by heavy waves, and the sand is not carried in to choke up the channelway. There is no "fretting" of the banks, as in the Mersey, for example. The Clyde Lighthouses Trust, which succeeded the Cumbrae Trust in 1871, immediately took steps to carry out the powers which Parliament had delegated to them, and appointed Messrs. Stevenson, of Edinburgh, their engineers. The improvement of the estuary between Port Glasgow and the tail of the bank involved, at the same time as the improvement of the estuary to Glasgow, the conservation of the entrances to the harbours of Port Glasgow and Greenock. These harbours required to have the benefits of a navigable fairway in close proximity, and yet the channelway for the ordinary river traffic to be sufficiently removed from the shore, that ships passing to other ports might be comparatively free from interruption from the local traffic to Port Glasgow and Greenock. The inconvenient curves round Garvel Point, and the bight at Cartsdyke, also required to be dealt with and made easier for the passage of large ships. A channelway, or rather what is really a ship-canal, has now been formed from Newark Castle (Port Glasgow) to Prince's Pier, Greenock, having nowhere a less depth than 23 feet at low water of spring tides, with a minimum width at the bottom of 300 feet, and slopes of 100 feet on either side, having depths varying from 20 to 23 feet. Before this canal was begun the ruling depth at that part of the estuary was 12 feet. The curves at Garvel and Cartsdyke have been eased by fully one-half. These improvements, great though they are, cannot be taken as final, as the draught of ships is still on the increase, and perhaps at no very distant date further deepening and widening of this channelway may be called for by the shipping interest. This deep-water channel has been marked on its northern side by buoys and a lightship lighted by gas, while the southern side has also been similarly marked by buoys, and gas-lighted beacons and buoys. Pilots can, therefore, take vessels through the estuary at night almost as well as by day; and when fog obscures the lights, the fog signals at Kempock Point, Fort Matilda, Cloch, Toward, and Cumbrae, give their warning notes to the sailor that he is near them.

The removal of wrecks becomes sometimes a serious matter in such navigations. In the case of the "Auchmountain," lying as it did in good anchorage ground, the wreck had to be repeatedly tackled with explosives, and, finally, on the suggestion of our firm, was covered up by dredgings, which has made the anchorage a perfectly safe one.

The tidal flow has been greatly facilitated by the dredging works having caused the tidal flow at Port Glasgow (where the Clyde Lighthouses Trustees' works described were executed) down to Greenock, to be more distinctly that of the sea proper than what it was; and especially is this an improvement from a sanitary view, as it renders the admission of fresh water more rapid, although the actual gain is not so much as might be wished, owing to the counter-effects of the greater amount of sewage to be dealt with than in former days.

DISCUSSION.

The CHAIRMAN: Can you tell us the minimum radius of curvature adopted in the channel?

Mr. C. A. STEVENSON: I think it is 1,200 yards.

Mr. W. H. HUNTER: What is the bottom width of the channel with this 1,200-yard curve?

Mr. C. A. STEVENSON: About 400 feet.

Mr. VERNON-HARCOURT: Are you deepening it at the present time?

Mr. C. A. STEVENSON: No, it is maintaining itself.

Mr. VERNON-HARCOURT: Is there much silt or sand brought up by the tide?

Mr. C. A. STEVENSON: No; the Clyde Trust dredgings largely consist of sewage and washings from the streets.

The CHAIRMAN: I should like to express the thanks of the Meeting to Messrs. Stevenson for their Paper.

[Paper.]

WORKS FOR IMPROVING THE BILBAO RIVER AND MAKING AN OUTER HARBOUR; ALSO THE APPLICATION OF LARGE CAISSONS AS A BREAKWATER FOUNDATION.

By Señor Don Evaristo de Churruca, Chief Engineer of the Bilbao River and Harbour Works.

Introduction.

Having had the honour of being invited by the distinguished engineer, Mr. L. F. Vernon-Harcourt, in the name of the Organising Committee of the International Engineering Congress, to be held in Glasgow in 1901, to present a Paper on the putting in place of large caissons filled with concrete, such as are now being used for the construction of the Bilbao breakwater, I have thought it desirable to give first of all a general idea of the works executed by the Bilbao Harbour Board to improve the river and the bar, and then to follow this up with a description of the harbour of refuge in course of construction in the Bay of Bilbao. In building the main breakwater of this harbour, we met with such difficulties from the violent action of the sea during north-westerly storms, that we were compelled to use large steel caissons, which shall be described later on.

The Bilbao River and Works made to Improve it.

General Description.—The maritime part of the Nervion River, known as "Ria de Bilbao," and which forms its port, has a total length of 14 kilometres (8⅝ miles), the town being situated in the upper part. The Nervion River has a torrential character; and the quantity of water, which in summer time is as low as 4 cubic metres per second (141 cubic feet), rises sometimes to 1,600 cubic metres (56,500 cubic feet). Such heavy floods last only a short time, so that the ordinary volume of the stream is small, and therefore has little influence on the river navigation, which is kept up exclusively by the tidal waters. The range of the tide varies between 1·24 metres (4 feet 1 inch) and 4·60 metres (15 feet 1 inch), this latter corresponding to equinoctial spring tides under ordinary atmospheric conditions. The annual average of all the tidal ranges is about 2·76 metres (9 feet); the volume of water that enters the river in such a tide is about 8 million cubic metres (10,464,000 cubic yards); and rises to 12 million cubic metres (15,696,000 cubic yards) at equinoctial spring tides.

Defects of the River.—The oldest documents that mention the Bilbao River show that it was in a very bad condition for navigation, and that as far back as the sixteenth century works were carried out to improve it. It was most important to improve the bar, the conditions of which were such that, according to a document dated 1503, many vessels were wrecked on it, on account of the small depth over it and the shifting of its sandbanks, due to the violent action of the prevailing north-west winds. To remedy these defects, in that and the following centuries, quays were built to fix the mouth of the river; but these works did not give very permanent results, for until within the last twenty years the sandbanks have continued shifting; whilst the depth of water has been at times as low as 0·60 metre (2 feet) at low water of equinoctial spring tides.

In the river itself, from its mouth up to Bilbao, there were many obstructions to navigation, such as shallowness, sharp curves, and banks, all of which existed to within a few years ago, despite all the training-walls built in past centuries throughout its length.

Urgent Necessity for Improvements.—Such a state of things affected the trade of Bilbao very unfavourably; and the effects were more keenly felt when, in 1870, the exportation of iron ore for the Bessemer process of steel manufacture was commenced on a large scale. Many vessels entering the port could only go out at spring tides, when loaded with mineral; and if, as frequently occurred in winter, the sea was rough at the time, or the waves choked the river mouth with sand, these vessels could not get out for weeks. In the winter of 1875–76, the steamers were detained inside the river during three and a half months, although the largest did not draw over thirteen feet. This happened very often, and the vessels sometimes were compelled to unload part of their cargo so as to be able to get out. In consequence of this, freights became very high.

Creation of the Bilbao Harbour Board.—The Bilbao Chamber of Commerce, realising that such conditions could not continue, obtained leave from the Government in September, 1877, to create a Harbour Improvements Board, with power to levy certain dues on imports and exports for defraying the cost of improving the Bilbao River. In the following month of October, the Government appointed the Author of this paper as Director or Chief Engineer of the Harbour Works, and the Board was finally constituted in November, 1877.

Design and Execution of the Works.—On account of the different interests then existing in connection with the Bilbao River, due to the five mineral railways that run to it, and to the various ironworks established on its banks, it was decided to improve the river itself and the bar first of all, with as little delay as possible, leaving the construction of the outer harbour till later, especially in view of the fact that this latter work involved a large outlay of money which was not then available.

When those works were begun (and we shall not enter into a detailed description of them, as they do not concern the principal object of this Paper), they soon produced the desired effects. Most excellent results were obtained, especially at the bar, by building a training-jetty 800 metres (2,625 feet) in length on the left bank of the river mouth, and carrying it out seawards with a gentle curve. Formerly only two feet of water existed at low tides in the channel, which, moreover, was choked by sand during winter gales to such an extent that no vessels drawing over 12 feet could go out; whereas, after building the jetty, a channel along its whole length was easily maintained, with a minimum depth of 4 metres (13 feet) at low water of equinoctial spring tides. This enabled steamers drawing 22 to 24 feet to go in and out easily at high water of spring tides, and it was navigable at neap tides for steamers drawing 18 to 20 feet. (*See plan.*)

The works executed in the river itself did away with the sharp bends; and by dredging along 14 kilometres ($8\frac{2}{3}$ miles), the depth is maintained at over 4 metres (13 feet) at low-water spring tides along the whole length, so that steamers of 20 feet draught can now come up to the Bilbao quays; whereas formerly those drawing over 10 feet were debarred. With the above improvements, and especially with those carried out in the lower part of the river, where the principal mineral tips are situated, the traffic increased so much that in 1896–97 the total imports and exports reached 5,792,804 tons, apportioned as follows: 4,954,490 for exports, and 838,314 for imports; whereas in 1863 the total was only 218,000 tons. The average capacity of the steamers that enter the river is more than three times what it used to be in 1878. All this has brought an enormous reduction in freights, and a great extension in the working of the mines in this region, which are the fundamental cause of the great development that has taken place in railway, industrial, and shipping undertakings in Vizcaya. In support of the statement we have made concerning these satisfactory results, the following paragraph may be quoted from Mr. Edward Wood's address to the Institution of Civil Engineers in London, on November 9, 1886:—

"Owing to the facilities now given, Bilbao ore, which in 1872 realised 35*s.* per ton delivered at our ports (one-half the cost representing freights), is at the present time landed at South Wales (where the import is one million tons per annum) at a cost of from 10*s.* to 10*s.* 6*d.* per ton, including freight, this not exceeding 4*s.* per ton."

The total cost of the works for improving the bar and the river, including dredging, buoys, electric lighting, cranes, sheds, etc., amounted to about thirteen million pesetas (£433,333*).

Outer Harbour.

Necessity of Building a Harbour.—The great increase in traffic that followed the river improvements, and the resulting income at the disposal of the Harbour Improvements Board, led them to consider the advisability of building the outer harbour as a necessary complement to the work done in the river. As the river mouth is directly exposed to the north-westerly winds, in spite of the improvements realised, the entrance of steamers continued to be dangerous during bad weather. This defect could only be removed by the construction of a breakwater that would shelter the river mouth; and as in doing this it was possible, at the same time, to create a large outer harbour for the use of Transatlantic steamers at all states of the tide, the following plan was studied, and was approved by the Government on June 29, 1888.

General Plan of the Works.—The outer harbour is enclosed from the open sea by two breakwaters: (1) The west breakwater, 1,450 metres

* The conversion into £ sterling is based on the rate of 30 pesetas = £1.

(4,757 feet) long, is formed by a straight portion, 950 metres (3,117 feet) long, running out from the coast at right-angles to the north-west, followed by an arm of 500 metres (1,640 feet) at an angle of 165° to the first length. This deviation is made in order to give a better shelter to the steamers inside. (2) The eastern breakwater, called the counter-mole, 1,100 metres (3,610 feet) long, running out from the coast in a westerly direction. Between the ends of the breakwaters there is an entrance 600 metres (1,970 feet) wide, so situated that the swell of the sea coming through it may be as small as possible, and make the entrance and exit of ships quite easy. In view of this latter consideration, it would seem that it would have been better had the entrance faced north-west; but the eastern breakwater would then have had to start from the Point of San Ignacio, and under these conditions the waves in north-westerly gales would very likely have entered the harbour, and also the heavy ocean waves, dashing against both breakwaters, would by reflection have met precisely at the entrance, and there have formed dangerous rising and breaking waves. We tried to get over these drawbacks by the plan that we have adopted, in which the waves have a free space of 1,150 metres (3,773 feet) wide to spread over, and then go and break against the rocks and strand of the east coast, without producing dangerous recoiling effects at the entrance of the harbour; in fact, waves can only come in by lateral transmission. (*See plan.*)

With the experience gained with the work, so far as completed up to now, the solution adopted has given excellent results; for the steamers go in and out quite freely during gales, and are quite in shelter behind the breakwater.

The area protected by the two breakwaters is 300 hectares (741 acres) at low water, and of this no less than 205 hectares (506½ acres) have a depth of between 5 and 14 metres (16 feet 5 inches and 46 feet) at equinoctial low-water. The first breakwater is, as will readily have been understood, the more important of the two. It rests on a bottom formed of mud mixed with sand, except near the coast, where the rock is uncovered; and it was therefore clearly indicated that the foundation of the superstructure should be formed with a sorted rubble, or a rubble and concrete-block mound. Moreover, as there were few days in the year during which it would be possible to work with divers for building a masonry wall founded under low-water, we decided to build the superstructure from the level of low-water, and to let it rest on a large mound of concrete blocks of 30 to 50 cubic metres (39¼ to 65½ cubic yards) each, and 6 metres (19 feet 8 inches) deep, which in turn would rest on a large mound of sorted rubble. These blocks, made with Portland cement, were deposited at random, this system having the advantage that it could be carried on rapidly, and that the very disorder of the stones and blocks would help a great deal to break the force of the sea.

Execution of Breakwater.—The contract for the work was entrusted to Messrs. L. Coiseau, Couvreux fils, and Felix Allard, on October 25, 1888. The work of depositing in place the foundation of rubble and concrete blocks was carried on rapidly; and after two winters, when it was clear that all the blocks had settled properly, we began building the superstructure, after having carefully filled up with rubble all the interstices between the big blocks, and covering the whole with a levelling bed of concrete. The superstructure itself was 12·20 metres wide (40 feet) at the base, tapering to 10·20 metres (33 feet 4 inches) at the top, and was 6 metres (19 feet 8 inches) high. This work was surmounted by a footway formed by a Portland cement concrete wall 4 metres (13 feet 1½ inches) wide and 3 metres (9 feet 10 inches) high, which in turn was sheltered from the open sea by a strong parapet 1·50 metres (5 feet) thick and 1 metre (3 feet 3 inches) high. The base of the whole structure was protected on the sea side from undermining by a large concrete toe. The main wall itself was formed by two face-walls of Portland cement concrete blocks, each 3 metres (9 feet 10 inches) long by 1·50 metres × 1 metre (5 feet × 3 feet 3 inches), placed as headers and stretchers and filled in between with a quick-setting concrete hearting. (*See section of breakwater.*)

Damages.—The building of the superstructure was begun in 1891, at the portion resting directly on the rocks of the coast, and on bags of Portland cement concrete when the rocks were under water. All this part of the work proceeded satisfactorily, but when the superstructure was extended over the base of rubble and concrete-block mound for a length of 127 metres (417 feet), the waves during a strong gale, between the 19th and 21st of November, 1893, undermined the facework along a length of 80 metres (262 feet) on the sea side, and opened a large breach in it.

After having carefully examined the damage caused, we came to the following conclusions:—(1) That the foundation of rubble and blocks, which had in the course of two winters acquired stability, lost it the moment it became covered by the superstructure. The waves that came with great force, striking against the breakwater and rising as much as 20 metres (65½ feet) in front of it, disturbed, in falling back, the 50 cubic metre (65½ cubic yards) blocks that formed the outer berm and sea slope. (2) Once these large blocks removed, the action of the waves followed, drawing out all the rubble that we had placed in the interstices between the blocks, and then destroyed the outside protecting toe of the breakwater. (3) The breakwater, having lost its outward protection, soon lost also, by undermining, its outside facing blocks; and then the sea, being able to act freely upon the hearting of concrete, soon washed it away and opened large gaps in the whole work. As a consequence of these observations, we decided to provide against the undermining of the superstructure by forming its under part with large iron caissons 12 metres × 6 metres × 2 metres (39 feet 4 inches × 19 feet 8 inches × 6 feet 6½ inches) filled up with Portland cement concrete, and resting upon the previous foundation. This foundation was proposed to be carefully strengthened by filling with bags of Portland cement concrete all the interstices between the under blocks, and also by protecting the outer sea side with several rows of Portland cement concrete blocks of 30 cubic metres (39¼ cubic yards) carefully deposited side by side with a Titan crane. This plan was approved by the Government; but before carrying it out most of the summer of 1894 was employed in repairing damages done in the previous winter. We made the repairs in the same way as the work had been built; but we protected the whole of it with rows of 30 cubic metre (39¼ cubic yards) concrete blocks carefully deposited side by side, and carried up to a height of 7 metres (22 feet 11½ inches) above low tide. In finishing the summer work, and as a test, we placed, at the end of the breakwater, two of the above-described iron caissons filled with Portland cement concrete; and we built the superstructure over it, which formed, with the two filled caissons, one mass of not less than 800 cubic metres (1,046 cubic yards). This was also protected from the action of the open sea by a large number of concrete blocks.

The first gale occurred on November 12 and 13, 1894; it only removed six of the protecting blocks, but increased the stability of the others, for they became more closely wedged together. We at once placed six blocks to fill the gap that the others had left; and when, on the 15th of December, another storm came on, we observed that only one of the blocks had been taken away, so that we were inclined to believe that with such a large mass of blocks placed along the outer facing of the breakwater, the whole structure was perfectly protected from further damage. We were, however, soon undeceived by the storm of December 30 and 31, one of the fiercest ever known.

On that evening the action of the waves became so violent that all the mass of protecting blocks of 30 cubic metres (39¼ cubic yards), and of over 60 tons weight each, all laid with the crane with the greatest care one against the other, and against the facework, in two rows in width and depth, forming in all an apron 8 metres (26 feet 3 inches) wide and 5 metres (16 feet 5 inches) high, was completely carried away down the sea slope, leaving the toe of the superstructure unprotected, which was ultimately undermined and demolished. But the most remarkable feat of that storm was the removal of the large monolithic mass of 800 cubic metres (1,046 cubic yards) and of 1,700 tons weight, placed, as we have already explained, at the end of the work, which was carried 32 metres (105 feet) into the harbour. It is true that, before carrying that mass away, the waves must have begun by undermining it; but, nevertheless, this is one of the most notable feats which has happened in harbour works, and it may be compared to the one that took place in 1872 to the Wick breakwater, where the waves carried away a block 13·70 metres × 7 metres × 6·40 metres (45 feet × 23 feet × 21 feet 2 inches), weighing 1,350 tons. Still, this mass had been built with special care, resting as it did on large blocks set 18 feet under low water, and tied in all directions with iron bands.

It is to be noticed that the bay of Bilbao is very similar to that of Wick, both of them narrowing in a funnel shape; and the waves that come in gradually rise in advancing, till they break with extreme violence against the works. We ought to add that the gale which played such havoc with the part of the breakwater superstructure that rested on loose blocks and stones, did absolutely no harm to the part near the coast, which rests on solid rock, nor to the block mound upon which the superstructure had not yet been built.

Alterations in Original Plans, and Adoption of Large Caissons.—From all that we have explained, we became convinced that it would have been a most daring plan to persevere in building the superstructure at low-water level on the foundation of rubble and loose blocks already laid, and that the wisest solution that could be adopted was to leave all that part of the work as an outer protection, and to build the superstructure further back, under its shelter.

In these conditions we deemed it sufficient to build the new superstructure at a depth of 5 metres (16 feet 5 inches) under equinoctial low-water level. Subsequent experience proved this depth to be quite sufficient, no doubt on account of the excellent protection afforded by the outer mound of rubble and blocks, which is in itself a kind of breakwater. On the other hand, for a work exposed so much to the action of the sea, where divers could only work for short periods, we had no confidence in an upright wall made with blocks, whether laid horizontally or inclined, because of the risk of the work settling owing to its height, and to the fact that it reposed on a rubble mound built upon such soft ground. We therefore proposed to the Government, in accord with the contractors, to build the superstructure upon large steel caissons filled with Portland cement concrete, resting 5 metres (16 feet 5 inches) below low water, a modification of the system unsuccessfully tried in 1894, which consisted of steel caissons placed at the bottom of the superstructure, 1 metre (3 feet 3 inches) above equinoctial low water. In this case, however, the caissons were founded 5 metres (16 feet 5 inches) below equinoctial low water, and were sheltered by the mound already constructed, so that the conditions of stability were greatly increased. We ought also to add that in 1892 we had proposed, and it had met with the approval of the Government in 1893, to build the pier-head of the counter-mole on one large caisson, 18 metres (59 feet) in diameter, 10 metres (33 feet) in height, placed 8 metres (26 feet 2 inches) below low water; and in July, 1894, it was decided to build the breakwater head in the same way, but with a caisson 27 metres (88 feet 7 inches) in diameter. The system we proposed, therefore, of building the whole pier upon caissons, accepted by the Government on June 15, 1895, had been already well thought out and tried in these works. (*See sections.*)

We decided to build the new breakwater at a distance of 47·69 metres (156 feet 6 inches) from centre to centre behind the first one, principally in order to leave between the two works an interval 30 metres (98 feet 5 inches) wide, where the waves, after breaking over the first line of blocks, would fall and lose most of their force in entering deep water, and also, to provide room for a tugboat, so as to facilitate the transport and deposit of the caissons. We also decided to employ caissons 13 metres × 7 metres × 7 metres (42 feet 7 inches × 23 feet × 23 feet), so that, when placed at a depth of 5 metres (16 feet 5 inches) below equinoctial low tides, they would emerge two metres (6 feet 6½ inches), as it was necessary that the top of the caissons should be above the water-level at low tide, to enable the work to be carried on inside. It was proposed to build them on the river bank. Their weight was estimated at about 30 tons, and their immersion in the water at 32 centimetres (12½ inches); but before towing them to the breakwater, they were to be ballasted with a layer of Portland cement concrete 1·50 metres (5 feet) thick, which would immerse them 3·40 metres (11 feet 2 inches). The caissons themselves were to be made of Bessemer steel plates, ¼ inch thick, strengthened internally with a longitudinal lattice-shaped bulkhead, and two others placed crossways, forming between them six equal partitions, each containing two Portland cement concrete blocks of 30 cubic metres (39¼ cubic yards), namely, 4 metres × 3 metres × 2·50 metres (13 feet 1 inch × 9 feet 10 inches × 8 feet 2 inches). The rubble-stone bed, on which the caissons must rest, required levelling up by means of a diving-bell to the aforesaid depth of 5 metres (16 feet 5 inches) below equinoctial low water; and as soon as this operation was carried out, the caissons could be conveyed to their place, put into alignment, and then sunk by filling them with water. It was necessary to fill these caissons rapidly, so that the sea might not break them to pieces; and as it would have been a long and tedious process to fill them at low tide with concrete made *in situ*, we decided to deposit the two 30 cubic metre (39¼ cubic yards) blocks already referred to, by means of the crane, in each partition. This operation could be effected very rapidly; after which it would be necessary to run Portland cement concrete into the interstices between the blocks, so as to make one single monolithic block of 13 metres × 7 metres × 7 metres (42 feet 7 inches × 23 feet × 23 feet), say 637 cubic metres (833 cubic yards), 1,300 tons in weight. We may add that this filling in place could be done after the water had been pumped out from between the blocks, and that the whole caisson could be finished with a layer of cement concrete 0·50 metre (20 inches) thick, binding the different blocks together.

It will be seen that by this method the quantity of concrete to be laid *in situ* would be reduced to a minimum, that it could be deposited out of the water, and that, if in course of time the iron sheeting were to rust and break away, an enormous monolithic block of concrete would always be left, strengthened throughout its mass by iron ties, the resistance of which under similar circumstances would be far superior to anything that had been done in this class of work up to now.

It was proposed to carry this foundation up to 2 metres (6 feet 6½ inches) above low water of equinoctial spring tides, and to build the breakwater superstructure upon it, formed by two walls made with Portland cement concrete blocks of 30 cubic metres (39¼ cubic yards), namely, 4 metres × 3 metres × 2·50 metres (13 feet 1 inch × 9 feet 10 inches × 8 feet 2 inches), each, and filled in between with rapid-setting concrete. This would bring the work up to 7 metres (23 feet) above low tide; and a quay could be established at this level, running the whole length of the breakwater, which would be protected from the sea by a strong parapet, 2·50 metres (8 feet 2 inches) wide, 1·50 metres (5 feet) high, and bound to the main work by strong wrought-iron ties.

We decided to finish the upper part of this sheltering wall by rounding it off; and we abandoned the projecting coping, which we had designed for the original superstructure to throw the waves back into the sea, because we found that in strong gales such a shape does not effectually protect the footpath, and has the disadvantage of increasing the recoil of the waves against the foundations of the breakwater. With the shape adopted, very large waves pass freely over the breakwater wall without injuring the foundations, and they fall inside the harbour, where they have little or no effect.

The system of construction explained above has, in addition, the very great advantage of allowing the superstructure to be built in separate lengths of 7 metres (23 feet), so that they can settle quite independently on the mound. This was most important in the present case, where the foundation of the whole structure is formed of a mound of rubble resting on a soft bottom.

This general arrangement would have to be altered slightly near the coast, by employing shallower caissons, resting on concrete bags deposited upon the rocks

The estimated cost of the work is as follows :—

1. Outside protection works, including the rubble and block mound, and the part of the superstructure built according to the first plan *	Ptas. 13,550,472. 58 cnts. (£451,682).
2. Inside work, including foundation of rubble, caissons, superstructure, and protecting toe blocks . . .	Ptas. 17,582,227. 60 cnts. (£586,074).
3. Approach road from Santurce to the breakwater; lighthouse, and minor works	Ptas. 261,540. 23 cnts. (£8,718).
Total	Pesetas 31,394,240. 41 cnts. (£1,046,474).

This total was brought down to 28,882,698 pesetas (£962,756), the accepted tender ; and as the total length of the breakwater is 1,450 metres (4,757 feet), the cost per metre run comes out at a little less than 20,000 pesetas, which with the depreciation of the exchange represents 16,666 francs per metre run (£203 per foot run) ; a sum that is less than the cost of the breakwaters of Dover, Holyhead, Plymouth, and Cherbourg, although the one at Plymouth is built in shallow water, the one at Cherbourg in about the same depth, and the other two in slightly greater depths than the one at Bilbao.†

Execution of the Work.—As soon as the new plan was approved of, the contractors began to work to it ; since then (about July, 1895) they have been able to work every year from April 20 to September 29, that is for a period of about five months, the remainder of the year being employed in making block caissons, and other preparatory work for execution during the following summer. Up to the present, 150 caissons have been placed at the following rate :—

1895	13 caissons.	1898	30 caissons.
1896	25 „	1899	30 „
1897	28 „	1900	24 „

This is equivalent to a total length of 1,090 metres (3,576 feet).

Putting the Caissons in Place.—The experience gained in putting the caissons in place has led to the adoption of the following system :—The caissons first of all receive a ballast of concrete 1·50 metre (5 feet) thick, say 136½ cubic metres (178½ cubic yards) ; and they are then towed into place during the last two hours of the ebb tide, so that as much time as possible may be allowed for placing the caisson on its foundation and filling it, this latter operation requiring that the upper part of the caisson shall be out of water. The caisson is first brought against a caisson already in place ; it is maintained there in proper alignment by means of ropes, and also of the tug, the bow of which faces the open sea. The caisson is then sunk by pouring water into it with a centrifugal pump suspended from a Titan crane, and worked by an electric motor. If the motion of the caisson whilst it is still

* The conversion is established on a basis of 30 pesetas = £1, but the exchange varies from 28 to 35 pesetas to the £.

† M. Chevalier in his *Études faites en* 1858 *sur les travaux maritimes d'Angleterre*, published in the *Mémorial des travaux hydrauliques de la Marine*, gives the accompanying prices for the following completed breakwaters :—

Breakwater.	Per metre run. Francs.	Per foot run. £	Breakwater.	Per metre run. Francs.	Per foot run. £
Dover	33,200	404	Holyhead . . .	16,900	206
Portland (outer) .	14,000	170	Plymouth . . .	25,000	304
Alderney . . .	16,000	195	Cherbourg . . .	18,000	219

floating brings it out of alignment, we pump out a little water from it, and then sink it again. There are always little irregularities ; but these are easily corrected in the superstructure with the berme of one metre that has been left on each side. Once the caisson is in place, eight or ten of the twelve 30 cubic metre (39¼ cubic yards) concrete blocks are deposited in it by means of the Titan crane during the same low tide. During the following low tide, after pumping the water out of the caisson, the remaining blocks are inserted, and the filling concrete is run between them with the 0·50 metre (20 inches) layer on the top. All this work is generally completed during the first two low tides.

During the third low tide the construction of the superstructure, 5 metres (16 feet 5 inches) high, that rests on the caisson, is proceeded with. This superstructure is formed by two face-walls consisting of eight Portland cement concrete blocks, 4 metres × 3 metres × 2·50 metres (13 feet 1 inch × 9 feet 10 inches × 8 feet 2 inches), placed in two rows, breaking joints as headers and stretchers ; the space between the two walls being filled in with quick-setting concrete. If the weather is fine, the superstructure is finished during the fourth tide, with the exception of the parapet wall, which is only built when it is ascertained that each caisson has quite finished settling down. Therefore, weather permitting, all the work pertaining to one caisson is accomplished during four tides, that is, in two days. This work, representing about 1,004½ cubic metres (1,314 cubic yards), is made up as follows :—

		Cubic metres.	Cubic metres.
Interior of the caisson 13m. × 7m. × 7m. (42′ 8″ × 23′ × 23′)	Bottom ballast, 13m. × 7m. × 1·50m. (42′8″×23′×4′11″)	136·50 (178·54 cub. yds.)	637·00 (833·17 cub.yds.)
	Twelve blocks, each 30 c.m. (39.24 cub. yds.) . .	360·00 (470·88 cub. yds.)	
	Filling up concrete and top layer	137·78 (180·20 cub. yds.)	
	Capacity of iron bulkheads and wooden props . .	2·72 (3·55 cub. yds.)	
Superstructure, not including the parapet.	Eight blocks, each 30 c.m. (39·24 cub. yds.) . .	240·00 (313·92 cub. yds.)	367·50 (480·69 cub.yds.)
	Filling in with quick-setting concrete . . .	127·50 (166·77 cub. yds.)	
Total cubic metres			1004·50 (1313·86 cub. yds.)

The time employed by the divers in levelling up the foundation for one caisson varies as a rule between one and two days, so it follows that a length of 7 metres (23 feet) of breakwater can be built every three or four days. On account of the weather, however, and unforeseen breakdowns, the work does not always proceed at that speed ; in fact, sometimes during one month only the superstructure corresponding to four caissons has been built, and during other months a maximum of nine caissons has been reached.

As soon as a length has been built in the way described above, the rails for the Titan crane are laid upon it, and the work of the next caisson is proceeded with. At the end of the season, all the 30 cubic metre (39¼ cubic yards) protecting blocks are placed on the outside, and at the foot of the superstructure ; and the Titan crane is brought back within shelter near the coast.

As this system has been tested during six winters without the slightest mishap, it can be safely recommended for seas as violent as those of the

Bay of Biscay. One of its principal advantages is the freedom with which each section of superstructure can follow the movements of the caisson as the latter settles on its foundation.

If, instead of building in the above manner, a breakwater superstructure is built upon a foundation of blocks, if the latter, however carefully set, rest on a rubble mound or on soft ground, there is every chance that they will settle unevenly, so that the upper part, being built solid with mortar and not able to follow these movements, remains rigid like a beam, and allows the sea to wash out the foundation blocks from those portions which are not weighted by the upper part. The sloping-block system has been tried to remedy this; but even if the unequal settlement is thereby to a certain extent counteracted, the defects of the unequal settling are not remedied at all; whilst the system is unsatisfactory for heavy seas like those of the Bay of Biscay. In proof of this, we have the works of the neighbouring port of Castro-Urdiales, where a breakwater far more sheltered than that of Bilbao is being built; it rests on very large sloping blocks, and the short length already built was completely wrecked in January, 1900.

From the moment a caisson is first placed to the time when the superstructure resting upon it is finished, it settles about 0·20 metre (8 inches); later on, with the weight and motion of the crane, and the action of gales during the winter, the caisson settles another 0·40 metre (15½ inches) making about 0·60 metre (23½ inches) in all. This will give an idea of what would happen with a system which did not offer such facilities for settlement as are possessed by the system herein described.

After two winters, the caisson may be considered to have entirely settled down; the joints between them, which are about 0·30 metre (11¾ inches) wide, are then filled up with cement concrete, and the parapet wall is built. Since 1898 many steamers use the breakwater already built as a shelter; in fact, during the very violent storms of January, 1900, twenty-three steamers and four sailing vessels took refuge there in complete safety. We anticipate that the breakwater will be completely finished in 1902, with the exception of some accessory works.

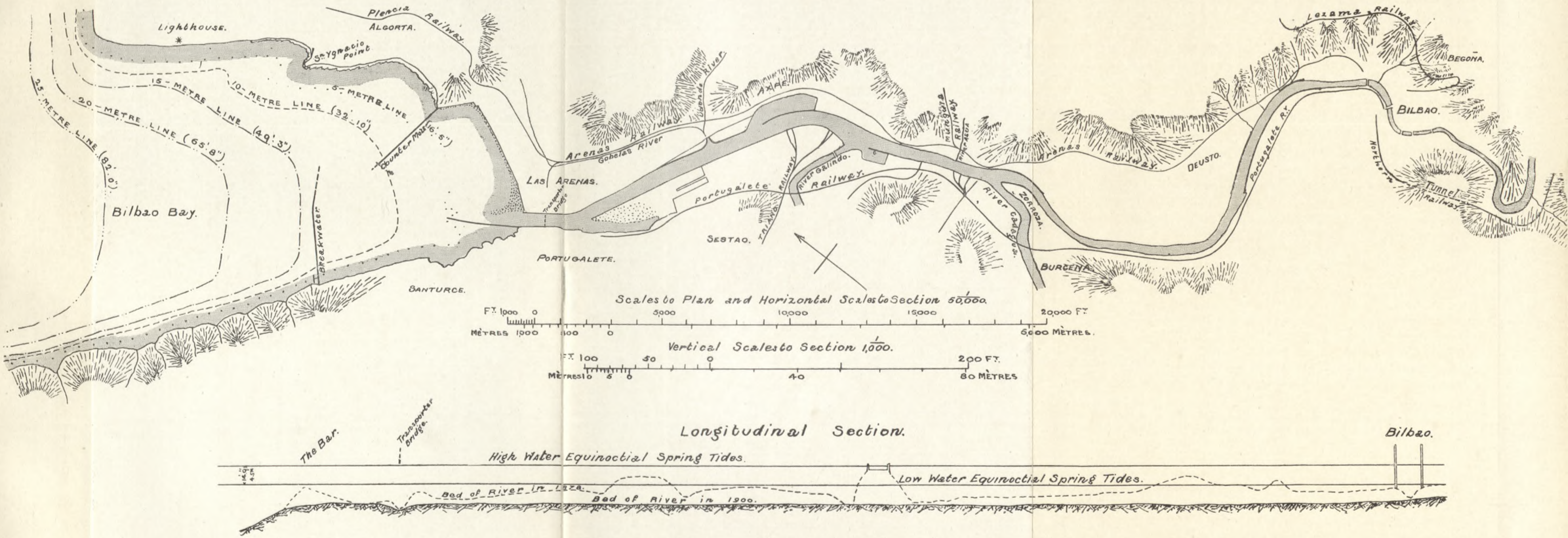
We may add that the depth of 5 metres (16 feet 5 inches) below low water of equinoctical spring tides was deemed sufficient for the caissons, because our breakwater is sheltered by the previous work executed in front of it, and by the interval between; but, without such protection, we should certainly consider this depth inadequate; and we are of opinion that in that case a depth of 7 to 8 metres (23 feet to 26 feet 3 inches) would be necessary.

Counter-Mole.—The construction of the counter-mole, or eastern breakwater, calls for no special remarks, because the waves run nearly parallel to it. It has been built on a foundation of rubble stone that reaches 3 metres (9 feet 10 inches) under low water of equinoctial spring tides. This foundation is covered with a bank, formed with bags of Portland cement concrete raised one metre (3 feet 3 inches) above low tide; and the outside is protected with 50 and 30 cubic metre (65½ and 39¼ cubic yards) concrete blocks. The superstructure, which rests on the bags of concrete, is built with block face-work and a concrete hearting deposited *in situ*.

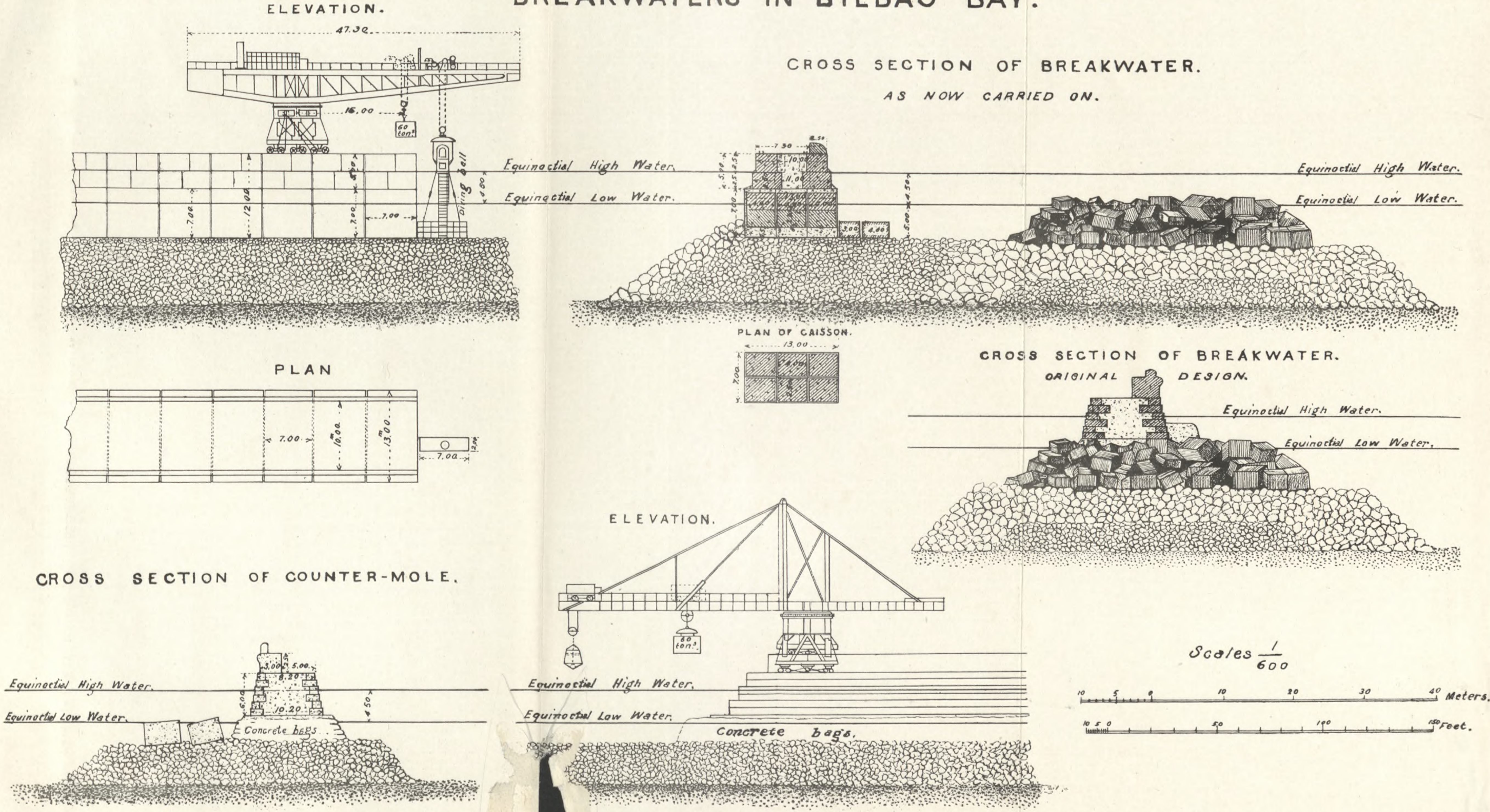
This work, with the exception of the lighthouse and minor details, will be finished in 1901. It is 1,100 metres (3,609 feet) long, and its cost is 8,116,764 pesetas (£270,559); that is, 7,379 pesetas per metre run (about £75 per foot run). This is only 36 per cent. of the cost per foot run of the western breakwater, which will give an idea of the relative importance of each work.

Contractors.—The contractors for the whole of the work are Messrs. Louis Coiseau, Abel Couvreux, and Felix Allard, who have shown great knowledge and capacity in organising and carrying out the work, and especially as regards the plant for making the concrete blocks and for conveying and setting them. We have already described these operations in the annual reports to the Bilbao Harbour Board; it is in these works that electricity has been employed for the first time for handling blocks up to 100 tons weight, and also for working the Titan cranes, up to 60 tons capacity, which the contractors designed and used in the construction of the two breakwaters.

BILBAO BAY AND RIVER NERVION.



BREAKWATERS IN BILBAO BAY.



[Paper.]

ZEEBRUGGE HARBOUR WORKS.

By MM. J. Nyssens Hart, Ingénieur en Chef honoraire des Ponts et Chaussées, Administrateur délégué de la Compagnie des Installations Maritimes de Bruges, and L. Van Gansberghe, Ingénieur principal, ffons d'Ingénieur en Chef, Directeur des Ponts et Chaussées.

The report drawn up by M. Piens, Ingénieur des Ponts et Chaussées, and by one of us for the VIIIth International Navigation Congress, held at Paris in 1900, gives all the details concerning the harbour now in course of construction at Zeebrugge, on the Belgian coast. The new name of Zeebrugge, given to the port of call, has been officially recognised. It was formerly incorrectly named the port of Heyst, although the boundary of that district is situated 1 kilometre (0·62 mile) away from the harbour. The jurisdiction of Bruges (Brugge in Flemish) has now been legally extended over the whole area of the harbour, in virtue of additional land granted to the town. This extension is now called Zeebrugge (Bruges-by-the-Sea).

The port of call is formed by a curved breakwater, starting from the sand dunes, and extending out to sea into a depth of 8 metres (26·24 feet), consisting of a sea wall and harbour wall, with filling between, forming a quay. It also is provided with an entrance channel and lock, which connect the roadstead sheltered by the breakwater with an inner basin in communication with the Bruges Ship Canal. The starting-point of the breakwater from the coast is situated 2,250 metres (7,380 feet) to the west of the Heyst drainage sluices. The breakwater curves round towards the east, the outer end running parallel to the coast-line, at a distance of 950 metres (3,116 feet) from low-water mark. The entrance to the approach channel, leading to the sea lock, is situated 850 metres (2,788 feet) to the east of the starting-point of the breakwater. A straight line drawn from the point of intersection of the axis of the channel with low-water mark in a N.E. by N. direction would, if prolonged, be a tangent to the extremity or head of the breakwater. The breakwater consists of three portions: the first portion on the beach is 232 metres (751 feet) long, and is solid embankment; the second portion, 400 metres (1,312 feet) long, in continuation of the first, is an open-work viaduct; whilst the third portion is a solid breakwater, 1,605 metres (5,264 feet) long. The total length of the breakwater, measured along the outside face, is 2,237 metres (7,337 feet).

The third portion of the breakwater comprises a quay 74 metres (242·7 feet) wide, bounded on the harbour side by a quay wall 1,271·4 metres (4,170 feet) long, alongside which there is a general depth of 8 metres (26·24 feet) at low water of spring tides, for a width of 300 metres (984 feet) from the wall. The breakwater encloses a roadstead of about 100 hectares (247 acres), which it protects from the prevalent southerly to north-westerly winds, and from the heavy gales blowing from S.W. round to N.W. It protects the entrance of the channel as far as N.E. by N., which is practically the extreme westerly point of the shoals in the offing; and it forms the boundary line, beyond which the sandbanks and shoals in front of the Zeeland Islands are a protection against rough seas during easterly winds.

The frequency and intensity of the winds on the coast are given in the following table, which embodies the results of twenty years' observations at Ostend:—

Frequency of Winds.		Frequency of Gales.	
N.	107	N.	4·1
N.E.	124	N.E.	4·4
E.	82	E.	1·0
S.E.	64	S.E.	0·2
S.	157	S.	3·5
S.W.	181	S.W.	20·8
W.	180	W.	11·2
N.W.	105	N.W.	8·6
	1,000		53·8

The construction of breakwaters by means of large concrete blocks is one of the subjects to be considered at the Glasgow International Congress of Civil Engineering. This system of construction has been adopted for the third portion of the Zeebrugge breakwater referred to above. This portion comprises two parts: the first is a breakwater and quay with a sea wall, 1,265 metres (4,149 feet) long, on the exposed side, which protects the filling forming the quay between the sea wall and the harbour wall; the second part, or outer breakwater, is 340 metres (1,115 feet) long. The base of the sea wall consists of monolithic concrete blocks weighing 3,000 tons; 25 metres (82 feet) long by 7·5 metres (24·6 feet) wide; and their height varies according to the depth of the sea, so that the top of all the blocks may be 1 metre (3·28 feet) above low-water level. The main body of the sea wall, 5 metres (16·4 feet) thick, is built on the top of these blocks; it consists of three courses of 55-ton blocks arranged as headers and stretchers, and built up to 7 metres (22·96 feet) above datum.* The joints of the blocks for the foundation and superstructure are closely packed with concrete and mortar. Above the level of + 7 metres (22·96 feet), the sea wall consists of concrete blocks moulded *in situ*, these forming a sheltering wall 4·8 metres (15·74 feet) high and 3 metres (9·84 feet) wide. The straight length of sea wall, which is the part constituting the outer breakwater beyond the quay, is larger; it is 9 metres (29·52 feet) wide at the base, and 6·3 metres (20·66 feet) wide in the middle; and the upper part of the wall is 4·5 metres (14·76 feet) thick. (*See plate*).

The outer breakwater terminates in a pier-head, the base of which consists of a single block, 16 metres (52·48 feet) in diameter, and 9 metres (29·52 feet) in height. Between the levels, 1 metre (3·28 feet) and 7 metres (22·96 feet) above datum, this block is 13 metres (42·64 feet) in diameter; and it is further reduced to 11·5 metres (37·72 feet) in diameter between the levels 7 metres (22.96 feet) and 11·8 metres (38·70 feet) above datum. A small tower, with a light, will be erected on the pier-head.

* Datum, or zero, is low water of spring tides.

Along the whole length of the solid portion of the breakwater there is a concrete parapet, 1·2 metre (3·94 feet) high and 1·2 metre (3·94 feet) wide; its summit is at the level of + 13 metres (42·64 feet). Under the shelter of this parapet there is a footway along the top of the sea wall, which forms a continuation of the footway along the sea side of the embankment across the beach and the open-work viaduct. A passage leading to the light on the pier-head is provided in the wall of the outer breakwater. The toe of the sea-face of the breakwater is protected from undermining by a mound of large rough blocks of Tournai stone, weighing from 300 to 2,000 kilogrammes (5·9 cwt. to 39·36 cwt.).

The quay wall, which protects the embanked portion of the breakwater on the harbour side, is built of concrete, like the sea wall; the base consists of blocks 25 metres (82 feet) long, laid on the sea-bottom, which has been previously dredged to a level of 8 metres (26·24 feet) below datum, for a length of 876·41 metres (2,876·6 feet), and to a level of 9·5 metres (31·16 feet) below datum, for a length of 393 metres (1,289 feet). These blocks are 9 metres (29·52 feet) wide at the base, and 6·2 metres (20·34 feet) wide at the top, with a batter of 1 in 10 on the outer face. Three courses of concrete blocks are then laid upon this foundation; two of the courses are 2 metres (6·56 feet) high, and one is 2·1 metres (6·89 feet) high; they reach the level of + 6·9 metres (22·63 feet). The coping is 0·4 metre (1·31 feet) thick. A culvert is provided in the top course of blocks, for carrying away the rain-water, and for laying down the various pipes necessary for the work of the port. The space between the sea wall of the breakwater and the quay, or harbour wall, is filled in with earth and covered with stone pitching, formed to a level of 7·3 metres (23·94 feet) above datum. There are three covered sheds on this quay, having their floors flush with the bottom of the trucks. These sheds are 95 metres (311·6 feet) long by 30 metres (98·4 feet) wide. A portion of the sheds is used as a booking-office for passengers, and as a Custom-house office. The quay is also equipped with lines of railway and eight electric overhead cranes.

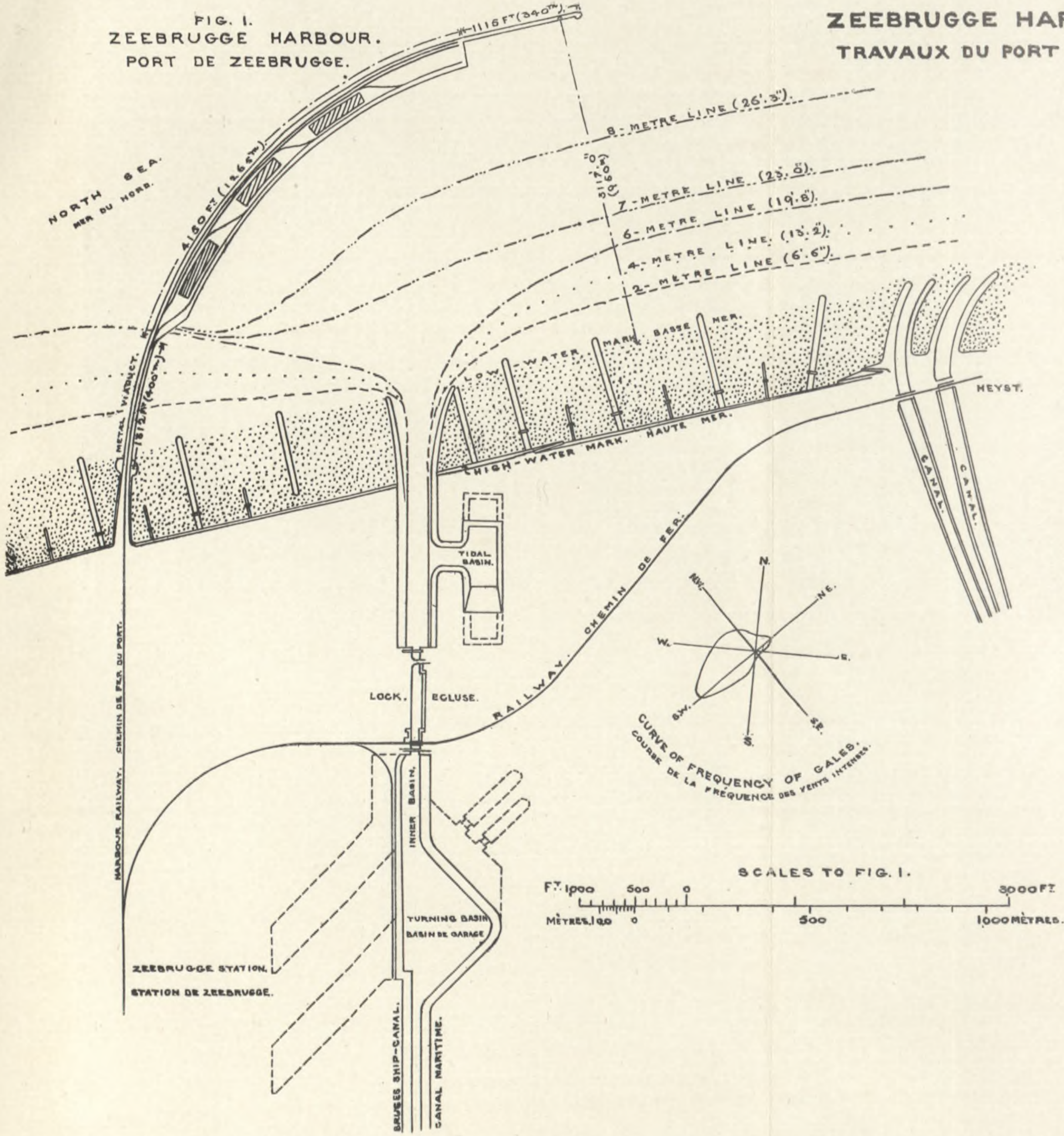
The work has been entrusted to M. L. Coiseau, engineer, of Paris, and M. J. Cousin, engineer, of Brussels, who are, moreover, the designers of the scheme. In working out the details of the scheme, these engineers had to devise the best means to adopt for constructing the sea wall and harbour wall of the quay portion of the breakwater, and the outer breakwater, both with a view to the stability of the work and the time required for carrying it out, as well as its initial cost and expenses of maintenance. The selected design, due to M. Coiseau, is a judicious extension of the principle so successfully applied at Bilbao. As the sea-bottom at Zeebrugge is never lower than 8 or 9 metres (26·24 to 29·52 feet) below low water, M. Coiseau decided to do away entirely with a rubble-work foundation, and to increase the height of the caissons and deposit them directly upon the sea-bottom, which consists of clayey sand.

The design, therefore, adopted for Zeebrugge consists of a series of sections varying from a few metres to 25, 30, 40 and 50 metres (82, 98·4, 131·2, and 164 feet) in length, and varying from a few metres to 10 and 12 metres (32·8 to 39·36 feet) in height, with proportionate widths. These sections are concrete or masonry blocks with large cavities in the first instance, providing sufficient displacement, in comparison with their weight, to enable them to be towed out floating into position, without danger of sinking during their voyage; and they are then sunk and filled up with concrete. According to circumstances, these blocks can either be built in iron or wooden caissons remaining part of the blocks, or else the iron or wooden caissons can be in the form of removable coffer-dams, similar to those employed in the construction of the Antwerp quays in 1880. In the case of the port of Zeebrugge, the concrete blocks are made in iron caissons, forming part of the mass. This is the most rapid and safest method of construction. Four sizes of blocks are employed; but it will suffice merely to describe those used for the outer solid breakwater beyond the quay. The caissons or foundation blocks are 25 metres (82 feet) long, 9 metres (29·52 feet) wide, and 8·75 metres (28·72 feet) high, which represents a cubic capacity of nearly 2,000 metres (2,616 cubic yards), and a weight of about 4,500 tons for each block forming a section of the wall. The lower part of the caissons has a cutting edge to enable it to penetrate into the ground.

These blocks are made in the basin forming the inner harbour just above the sea lock. The 116 blocks for the sea and harbour walls and outer breakwater were made in less than two years; this work represents the handling of 4,700 tons of iron, and 80,000 cubic metres (104,640 cubic yards) of concrete. The moulded concrete forming the shell of the blocks is made of 1 part of cement, $2\frac{1}{2}$ parts of sand, and $6\frac{1}{10}$ parts of broken porphyry. Suitable moulds are employed to give the arched form to the concrete shell, as shown by the sections on the accompanying plate. An orifice is provided in the shell of each compartment for letting in the water to sink the block. The hollow block is towed into place by hawsers passing over windlasses. When it arrives at the spot where it is to be sunk, it is inserted between two girders connected together, which guide it into its exact position against the last block of the finished wall. The hollow block is then sunk by removing the plugs in the orifices of the shell, so that the water can enter and fill the three chambers. When sunk the block first bears upon its cutting edge, which penetrates the clayey sand of which the sea-bottom is composed. The whole weight of the block is borne by the cutting edge, so that if the surface of the ground is at all uneven, the block has time to level it and to settle evenly without risk of breaking, during the time the cutting edge is working into the soil. When the block has been deposited upon its foundation, it is filled with concrete by means of skips of 10 cubic metres (13·08 cubic yards) capacity, which open at the bottom directly they begin to be drawn up. The final metre of thickness, consisting of concrete with a large proportion of cement, is deposited out of water at low tide. The toe of the block facing seawards is then protected without delay against undermining by the tidal currents and the recoil of the waves. This is done by depositing large rubble blocks for a width of 15 metres (49·2 feet), of sufficient thickness to prevent any chance of the cutting edge of the block becoming exposed. When the sea-bottom upon which the block is to be founded is uneven, it is levelled by means of rubble deposited by hopper barges. The 55-ton blocks for the superstructure are then laid on this foundation when the tide serves. The upper wall and the concrete parapet moulded *in situ* are then built upon these blocks.

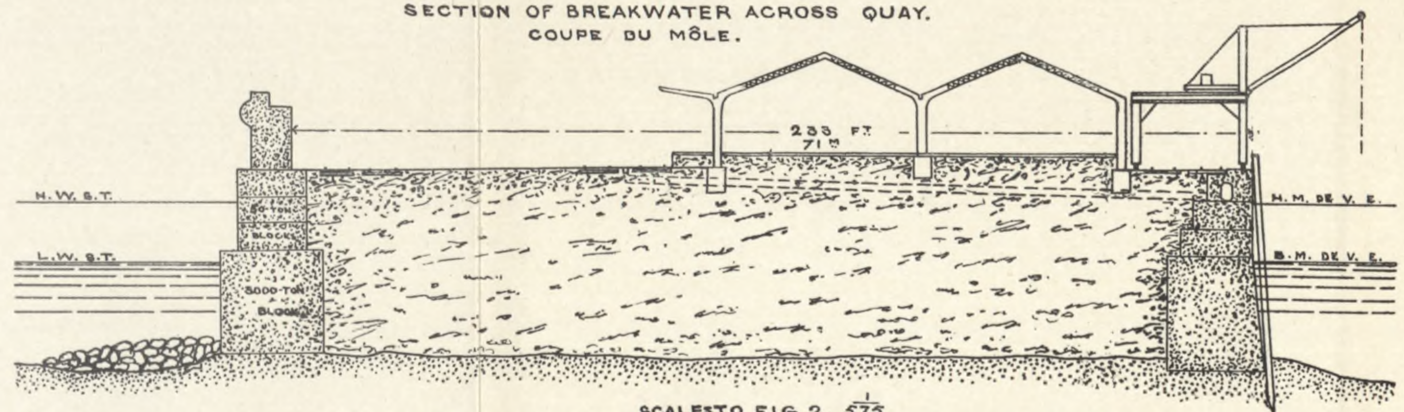
ZEEBRUGGE HARBOUR WORKS.
TRAVAUX DU PORT DE ZEEBRUGGE.

FIG. 1.
ZEEBRUGGE HARBOUR.
PORT DE ZEEBRUGGE.



SCALES TO FIG. 1.
FT. 1000 500 0 500 3000 FT.
METRES 100 0 500 1000 METRES.

FIG. 2.
SECTION OF BREAKWATER ACROSS QUAY.
COUPE DU MÔLE.



SCALES TO FIG. 2. $\frac{1}{575}$
FT. 50 0 50 100 FT.
METRES 10 5 0 30 METRES

FIG. 3.
SECTION OF OUTER BREAKWATER.
PROFIL DE LA JETÉE BRISE-LAME

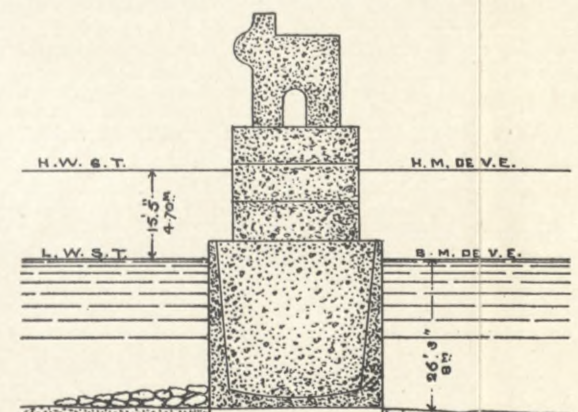
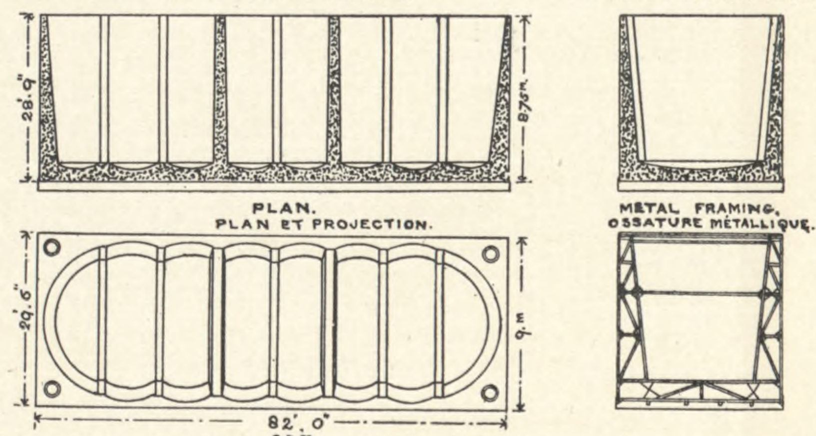


FIG. 4.
CAISSON FOR FOUNDATION BLOCKS.
CAISSON DES BLOCS DE FONDATION.

LONGITUDINAL SECTION.
COUPE LONGITUDINALE.

CROSS SECTION.
COUPE TRANSVERSALE.



SCALES TO FIGS 3 AND 4 $\frac{1}{400}$.
FT. 10 5 0 50 100 FT.
METRES 10 5 0 10 20 METRES

The 55-ton blocks are set back 1·25 metres (4·1 feet) from the base, and the upper wall is set back 1 metre (3·18 feet) from these blocks, as shown on the section on the accompanying plate. This section has been adopted intentionally, in preference to a sloping or curved profile, as these facilitate the upward run of the waves in rising above the parapet and causing a heavy recoil.

The new system adopted for this work, which has been described above, represents a type of breakwater which may be built comparatively quickly, without any special difficulties; the size of the blocks ensures great resistance to the action of the sea; and the cost of the works and cost of maintenance are no higher than for any of the other systems of construction generally adopted. Up to the present time four caissons have already been deposited; these form the starting-point, on the sea side, of the solid portion of the breakwater.

The work is stopped for the moment owing to the gale of January 27, 1901, which destroyed a part of the open-work viaduct, thus cutting off access to the solid portion already constructed, which is now isolated. The portion of the breakwater in progress, thus temporarily cut off, was not injured in the least by this gale.

DISCUSSION.

Mr. VERNON-HARCOURT : M. de Churruca states that during the last year they have deposited thirty-four of these large blocks in the main breakwater, and they hope to be able to complete the main breakwater next year. He has also explained that the counter-mole is very nearly finished ; and he has the honour to exhibit photographs of the caisson for the pier-head of the counter-mole, or eastern breakwater, which has been deposited in a depth of about 26 feet of water on a rubble mound. Portions are first filled with concrete blocks in the recesses of this caisson ; and the water is then pumped out, and the caisson filled up entirely with concrete. In that way it forms a kind of monolith of about 5,000 tons weight.

Mr. P. A. FRASER : During my residence at Genoa for two years I had the opportunity of witnessing two storms which affected the breakwater ; the original storm took place on the 28th November, 1898, and caused a breach in the mole 656 feet long, sweeping the parapet entirely away. As I was not then in Genoa I have no photographs of the state of the breakwater on that occasion ; but the work of repairing was commenced by the Government contractors, and was proceeding during the period I was at Genoa. During that time two further storms took place ; and I have brought photographs of these, which show the effect of the sea in moving the concrete blocks, weighing about 55 tons, of which the breakwater was originally constructed. This construction was very much like the Bilbao breakwater, the foundation being formed of large masses of rubble stone, with concrete blocks superimposed, weighing about 55 tons.

The CHAIRMAN : What was the depth below low water at which the foundations were laid ?

Mr. P. A. FRASER : I have not brought a section of the original breakwater with me, but I think it was about 29½ or 33 feet.

The CHAIRMAN : Are the blocks laid on rubble ?

Mr. P. A. FRASER : Yes.

The CHAIRMAN : What is the level of the top of the rubble bank ?

Mr. P. A. FRASER : It must be about 33 feet below high water ; there is only a range of tide of 18 inches in the Mediterranean there. According to the concensus of opinion, what happened during the storm was that, first of all, the rubble was excavated by the under-tow of the waves and then one end of the blocks was tilted up ; and when I photographed the breach, in 1899, a number of these 55-ton blocks were lying alongside the parapet, showing that they had been used as battering-rams, and had completely knocked over the parapet. Here is a proof, if such were required, that the use of heavier blocks is indispensable to overcome the force of the sea ; such a storm in the Mediterranean is a very rare thing, and happens only once in fifty years. In reconstructing the work, the contractor and Government engineers adopted the plan of constructing the blocks *in situ*, as it was seen that the blocks were not heavy enough; and, consequently, they abandoned the idea of making them ashore and transporting them by pontoons, as they had originally done.

Mr. VERNON-HARCOURT: What is the size of these new blocks?

Mr. P. A. FRASER: Perhaps double the size of the original blocks, about 100 tons, or rather more.

Mr. J. R. BATERDEN: We have reason to be thankful to M. de Churruca for the interesting Paper he has given us; for he has not only given us his experience of works that have been successful, but also of some of his failures, the knowledge of which is always of great advantage to engineers. I think the original depth of the top of the rubble mound below low water was 15 feet. The Author has shown us that it was not safe to found the new breakwater less than 16 feet below low water, even under the shelter of the old damaged pier; and if it had not been for the latter it would have been necessary to increase the depth at least 50 per cent. I am not quite certain whether, in the remarkable storm at Genoa referred to by Mr. Fraser, the depth of the rubble mound was about 30 feet below the water.

The CHAIRMAN: I think Mr. Fraser is not quite sure about it.

Mr. J. R. BATERDEN: It seems to me that not a single superstructure built upon a rubble mound, and finished in recent years, has not been more or less damaged; and I doubt very much whether a single breakwater of this type at present constructed will not, in a very short time, be damaged; we have had many lamentable instances of this on our own coasts. The only large sea-pier on the English coast which I know is being built at present on a rubble mound is at Peterhead, and the rubble mound there I think terminates at 32 feet below low water. I notice that in the Zeebrugge harbour works the large caisson is given as 26 feet 3 inches below low water. It seems to me that, whether you have a rubble mound or blocks, if the action of the waves scours away the toe of a rubble mound at a certain depth, it will also scour it away with large blocks; and I should not like to prophesy whether the consequences will be worse or better, though I should imagine it would be rather worse, and the damage more serious, with large blocks. I do not see the necessity, except in places where you want protection for a pier like the one at Zeebrugge, of taking the roadway of the pier at such a great height above high water. It is not only much more costly in construction, but it also detracts very seriously from the stability of the pier, seeing that the waves have a very much greater power against the higher construction than against the lower. If a pier were raised only a few feet above high water, and the waves were allowed to pass over it, the effect on the interior of the harbour would be comparatively slight at a short distance in; I think that was mentioned in regard to the pier at Colombo.

It is a pity that the large piers at our own ports, which are constructed at such a cost for the convenience of visitors, should be a source of weakness to the harbour itself. At Blyth we are making a pier in a depth of 18 feet at low water on the top of rock, and the solid portion of the pier is only taken about 2 feet above high water; there is an open gangway to provide accommodation for rocket service and lighthouses, 14 feet above high water;

and although the entrance channel is only 400 feet wide, the effect of the water falling over this pier is very small. I should like to ask the Author for information about the proportions of the materials in the concrete blocks; for of recent years there has been a certain amount of disintegration in the blocks used for sea works. As to the entrance of Bilbao harbour, it seems to me a very awkward one to enter. The Author says the waves run practically parallel to the eastern pier; if so, a vessel entering the harbour is broadside on to the waves, and when she comes in, she has to turn again to get inside the entrance pier of the river; but there may be some good reason for this. I have had the pleasure for several years of reading M. de Churruca's interesting reports on this harbour; and it is satisfactory to observe the enterprise of the contractors of the works in providing electric plant, the first, I believe, in connection with a work of this kind. I only hope the pier will be finished next year, and that it will be a successful work.

M. MENDES GUERREIRO : Il faut reconnaître que les procédés de construction concernant les ports de Bilbao et de Zeebrugge, sont à peu près identiques quant au fond.

On a cité également le port de Gênes comme rentrant dans le même système ; et des accidents sont arrivés également au port de Leixoes, près de Porto. Tous ces accidents sont dus au manque de protection du côté extérieur ; et, à cet égard, le port de Bilbao, et les travaux de défense exécutés au port de Leixoes près de Porto, paraissent présenter le plus de sécurité, car on y a abandonné complètement l'ancien mode de travail. On a construit à Bilbao des blocs de deux à trois mille tonnes, terminés par un bloc unique qui pèse plus de cinq mille tonnes. C'est d'ailleurs le système suivi à Zeebrugge, mais qui n'y présente peut-être pas les mêmes garanties de sécurité, à moins de construire des blocs à l'extérieur dans les 1,600 mètres (5,248 feet) de longueur du môle. Il y a là une certaine longueur qui ne paraît pas pouvoir présenter assez de garanties contre le gros temps en mer. Avant de se prononcer à cet égard, il convient cependant d'attendre les explications de M. Van Gansberghe. Je dois ajouter que chez nous l'électricité n'est pas employée pour le mouvement des appareils dans tous les travaux. Dans les ports de Gênes et de Porto, ce sont les parties supérieures qui ont été atteintes parce qu'elles ont été mal revêtues ; elles n'avaient pas assez de force pour briser les lames qui, passant par-dessus le parapet, détruisaient le tout, et parfois même la partie intérieure du môle.

M. DE CHURRUCA : A mon avis, les digues qui sont établies sur des enrochements, ou directement sur un terrain compressible, doivent être formées par tronçons indépendants les unes des autres, si elles sont exposées à une mer violente, pour que les tassements s'accomplissent en toute liberté. Je crois que la mer est beaucoup plus violente à Bilbao qu'à Zeebrugge, et qu'en ce dernier endroit il ne sera donc pas nécessaire de prendre autant de précautions.

M. VAN GANSBERGHE : Je suis d'accord.

Mr. VERNON-HARCOURT : I have had the opportunity of seeing the works at Zeebrugge on two occasions. On my first visit, in 1898, the caissons were being constructed in the inner part of the canal, inside the sea-lock ; and the lock was in course of construction. On the second occasion, last summer, I had the opportunity of walking along the open viaduct, and of seeing four caisson blocks which had been recently put in place at the commencement of the solid breakwater.

The cases of Bilbao and of Zeebrugge seem to me somewhat different, on account of the different exposures of the two sites. That, of course, is a governing factor with regard to works in the sea. You may construct a breakwater, quite strong enough on one site, which would be destroyed on another. The depth of the water at Zeebrugge, even at the outer part and in the sea beyond, is not nearly so great as at Bilbao; but, on the other hand, the blocks that have been made at Zeebrugge are very much larger than the blocks which have been deposited at Bilbao, except the caisson block for the pier-head of the counter-mole. The systems of construction of the two breakwaters are, indeed, somewhat different. The Bilbao breakwater is what I would term the mixed system of breakwater, with a rubble mound and superstructure. The Zeebrugge breakwater, on the contrary, is practically an upright wall. If an upright wall can be built in a solid mass, that is undoubtedly the best form of breakwater; because, though it may be absolutely necessary to deposit a rubble mound in very deep water, to bring up the foundations for the superstructure to a high enough level to deposit blocks for the superstructure, yet, if the water is shallow enough for you to be able to build your breakwater solid from the bottom, and the sea-bed on which it stands is not liable to erosion at its outer toe, then, undoubtedly, a perfectly solid breakwater is the better of the two. Mr. Baterden has referred to the erosion of the rubble mound in the mixed type of breakwater. Very early in my professional career, I had occasion to notice that very clearly at the Alderney breakwater, which, instead of being situated in a depth of 50 feet, extends out to a depth of 130 feet at low water, and faces the open Atlantic. Every winter there was a certain amount of scouring away of the rubble mound, near the sea face of the superstructure, by the recoil of the waves in storms. But the question was asked, to what depth would it be necessary to keep down the rubble mound so that it might not be scoured away? The requisite depth depends on the exposure; and with regard to that the practice is interesting. Mr. Baterden said he believed that no breakwater formed with a superstructure on a rubble mound would be likely to stand. It is to be hoped that that prediction will not be fulfilled, because, last year, I saw at Havre a breakwater in construction with a superstructure upon a rubble mound protected with concrete blocks, in which the superstructure was, rather to my surprise, founded at low-water level. Again, I think at Boulogne, the superstructure is rather above low-water level than otherwise. I confess that I should not feel very happy in building a superstructure at, or even near, low-water level, if it were exposed to severe storms. Havre is, indeed, not very much exposed, being only open to the English Channel; and therefore it is possible that the breakwater may stand, especially as the sea slope of the mound near the superstructure is protected with large concrete blocks.

At Colombo the superstructure was first founded about 20 feet below low water, then that was increased to 30 feet; and in the detached breakwater, in course of construction with sloping blocks, it is 30 feet. Mr. Baterden has also referred to Peterhead, where they have found it necessary to keep the rubble mound down in about 43 feet of water, so as to found the superstructure out of reach of the erosive action of the recoiling waves.

I quite agree with Mr. Baterden that it is desirable, if possible, to dispense with a parapet, because the amount of water that comes over into the harbour—when you raise the breakwater only 5 or 6 feet above high water—does no harm; whereas if this upper portion of the waves strikes and rises against a high parapet, the force of the blows of the waves on the breakwater is thereby increased, and the recoil of the waves and the consequent danger of erosion intensified. With regard to the objection raised against the entrance to the harbour of Bilbao, M. de Churruca has kindly informed me that the vessels do not make a right-angle turn as suggested, but come in at an angle of 15 degrees, and therefore do not have the waves right against their beam. They go in as near as possible at first to the extremity of the main breakwater, and then, in proceeding on their course, come close alongside the pier-head of the counter-mole; and in that way they enter the harbour partially under the shelter of the western breakwater, without making any awkward turn. A similar turn round was raised as an objection against the Zeebrugge breakwater. Before that curved breakwater was decided upon, there was a great discussion as to what form of harbour should be made; and even as late as last year, at the Paris Navigation Congress, there was a good deal of discussion in one of the sections as to whether that single curving breakwater provided a desirable form for the harbour. It would not have been a desirable form if the site had not been to a certain extent sheltered from the east; but the coast-line curves round on the eastern side, and the harbour is consequently fairly protected in that quarter, and it is under quite different conditions to the instance quoted at the Paris Congress as an example of the proper form of harbour, namely, that of the enclosed Ymuiden Harbour, on a straight sandy coast, at the entrance to the Amsterdam Ship Canal. Therefore it is quite possible that the form adopted for the Zeebrugge Harbour, although it does entail a certain amount of going round in entering the harbour, may be the best form for that particular locality. Dredging has to be carried on in the entrance channel of the Bruges Canal, which silts up to the extent of something like a metre in a year, and also in the site of the harbour, in order that the large caisson blocks for the breakwater may have a sufficient depth to be floated out. The dredging of this very fine silt has been very ingeniously effected by the contractors of the works, by so arranging a suction dredger that the inlet of its pipe may be kept at a constant depth of five feet below the surface of the silt, so that, instead of pumping up a mixture of silt and water, from which it is so very difficult to get the silt to settle in the hopper barge, silt alone is almost wholly pumped up; and therefore a much better return is obtained in the volume of liquid pumped up, and also such a large proportion of silt that it settles readily in the hopper of the dredger.

Mr. W. H. Hunter: I have had the advantage of inspecting the works of Bilbao and Zeebrugge, and I should like to add a word to the appreciation which has already been expressed concerning the mode of construction of the concrete blocks. One point has hardly been insisted upon, and it applies more particularly to the works at Zeebrugge, namely, that the steel caissons are of the most slender construction, the very minimum of material being employed;

the steel-work, although it is to a certain extent stiffened by intercostal bracing, is a mere skin, reinforced by concrete, of admirable design for the purpose of withstanding the stress upon the sides and bottom of the caisson. That appears to me to be a point of considerable importance in the construction of these blocks, for it certainly has reduced the cost of the caissons to a minimum, as the concrete which is required for weighting purposes is ample for stiffening purposes ; the same thing obtains at Bilbao. I think, having especial regard to the past, that it is hardly fair for us, in discussing these questions of flotation, concrete blocks, and kindred matters, to forget what one who has now passed from us, but whom some of us knew and admired, despite his eccentricities of manner, accomplished in respect of the flotation of concrete blocks ; I allude to the late Mr. Cunningham, of Dundee, who devised, and carried out to some extent, an extremely novel system of construction and flotation by hollow blocks.

The novelty lay in the sectional arrangement. He made a cover with an air-tight joint, and bolted it down to the block, and thus limited the rise of the water by means of the compression of the enclosed air, so that the block floated ; and he succeeded in doing that without any caisson or metal work whatever. My memory is, perhaps, not absolutely reliable upon the point, but I believe he got up to blocks of 300 to 500 tons ; and it is obvious that, as far as size is concerned, the system has very little—if any—limit.

I noticed one point at Zeebrugge which applies more particularly to that work than to the work at Bilbao, namely, the great area of absolutely flat bottom of these huge blocks in caissons ; if there is any inequality in the bed of the sea where these blocks are deposited, and if the blocks get out of position, or tilt in any direction, I do not see how they are going to be brought back into line. Now, in Mr. Cunningham's system, there was some possibility of adjustment of this nature : the openings were large enough to put a grab down, the chambers being afterwards filled solid with concrete, thus providing at each chamber a point of absolute bearing on the sea-bed. That seems the difficulty in this system of block construction, which certainly in other respects has advantages, and offers a means of escape from a difficulty which is sometimes considerable. Mr. Vernon-Harcourt tells us that he saw four of the blocks deposited when he was there last year. When I visited the place two years ago, there were no blocks *in situ;* but they were being built in the docks with a view to being floated out. I should have liked to hear from the Author of the Paper whether they have had any difficulty in respect to the deposit of these blocks.

Another point is the danger of erosion on the external side ; for I notice on the section a very small quantity of rubble deposit, which forms a sort of apron on the sea side of the breakwater. The quantity certainly does not appear to be very large, and the protection does not seem to be very efficient ; and, in my judgment, there is a danger of erosion from scour on the external side of the breakwater. The sand seemed to me, when I was there, as being particularly fine and mobile, little better than silt, and liable to be moved in very large quantities, and with great suddenness and rapidity—as some of us know to our cost. If anything of that kind were to take place on the outside of this curved breakwater, it might give rise to disaster ; the case of Bilbao is different, because the breakwater there is founded on a solid mound of rubble.

Mr. Vernon-Harcourt : Mr. Hunter has mentioned, with reference to the caisson blocks at Zeebrugge Harbour, that there probably might be a difficulty in founding them on an even bed. I happened to see these blocks at low water last year, and I must say that to a certain extent Mr. Hunter's views are borne out, because the tops of the blocks were not an even surface like one would wish to see, but to a certain extent tilted up ; though the intention is, where the sea bottom is uneven, to level it with rubble before depositing a block. I rather think the bed of the sea at Zeebrugge is not quite so mobile as Mr. Hunter would suppose. I fancy it is more an indurated silt mixed with sand, and not a very fine sand alone. Although I did express a view similar to that of Mr. Hunter's, as to the insufficiency of the rubble apron for protecting the toe along the sea face of the curved breakwater from scour, at the Paris Navigation Congress last year, I was assured that the kind of indurated clay which is the foundation of these caissons was hard ; and the contractor was of opinion that the protection afforded by this rubble on the outside of the breakwater would be amply sufficient to prevent scour of the bottom along the toe of the sea wall ; but of course that is a danger which requires to be guarded against.

Mr. W. H. Hunter : My experience is that indurated clay is a delusion.

M. Van Gansberghe : Le parapet construit à Zeebrugge est au côté du large du terre-plein du quai d'accostage. Il est nécessaire pour protéger la circulation des trains et le dépôt des marchandises. La même nécessité n'existe pas dans l'autre partie, mais là il s'agit d'abriter un passage d'accès au fanal à construire à l'extrémité du môle.

En réponse à M. Mendes Guerreiro, je dirai que nous avons déjà construit 100 mètres (328 feet) de jetée extérieure ; et que, depuis un an, les caissons munis de leur superstructure résistent très bien alors qu'ils n'ont que 7·40 mètres (24¼ feet) de largeur, tandis que dans la partie du môle formant brise-lames les caissons auront 9 mètres (29½ feet). Il y aura aussi des enrochements qui auront les dimensions voulues, si c'est nécessaire, pour garantir toute sécurité sur le développement complet de la jetée.

Je suis d'accord avec M. de Churruca quant à ses observations ; le fond est dur à Zeebrugge, argileux, contenant un peu de sable, de sorte que les mouvements de sable n'y sont pas à craindre du côté extérieur de la jetée. Une fois les caissons échoués, on constate qu'ils ne bougent plus ; les quatre caissons en place sont bien assis, et nous espérons qu'il en sera de même pour tous ceux que nous placerons encore. Après la pose, le couteau s'enfonce dans l'argile et le tout résiste convenablement. Les inégalités du fond sont rachetées par de petits enrochements bien arasés avant l'opération de l'échouage des blocs, lesquels sont conduits en place par temps calme, et coulés par étale de courant. On arrive ainsi à les aligner, et à les placer de niveau.

The Chairman : In closing the discussion and conveying our acknowledgments to the Authors of these two Papers, I may, perhaps, be allowed to make one or two remarks.

The system of foundation at Bilbao is on silt or sand, and on argillaceous sand at Zeebrugge. I notice that at Bilbao the distance between the low-water line and the top of the rubble mound is 16 feet, and that at Zeebrugge the distance between the low-water line and the argillaceous sand is 26 feet at the deepest point. These dimensions appear to me to be of the greatest possible interest, for I think experience at Bilbao demonstrates pretty clearly that if it were not for the protection of the outer mole, which has resulted from the failure of the original work, the new work would run very serious risks of the rubble mound being eroded and the superstructure would be more or less destroyed.

The chart, or the small portion of it which accompanies the plan, shows that the soundings are particularly deep at Bilbao. I find there is a depth of 25 metres (82 feet) of water within about 2½ kilometres (1½ miles) of the harbour, which indicates that the sea stroke must be exceedingly heavy upon the works at Bilbao. The exposure of these works is a combined factor of the fetch and the prevailing wind, and a function of the steep soundings; and these latter appear to be more favourable at Zeebrugge. Those two considerations were in my mind when I rose to speak, because a question of the failure of a most important breakwater at Tynemouth, near Newcastle, has recently been brought before me; and if any of the engineers present have the time, they will derive much benefit from a visit to the works which are now in course of construction there. The original design of the breakwater, built fifty or sixty years ago, was based upon a canon of engineering—which found acceptance at that time—that the action of the waves on a rubble mound was not apparent or of any importance when the depth was from 12 to 15 feet below low water; it was one of those canons which, unfortunately, were laid down with very little real basis of solid fact, but it was accepted in those days; and the original breakwater at Tynemouth was started at a depth of between 12 and 15 feet below low water. In the course of time those depths were recognised as insufficient, and the rubble mound already deposited, was lowered, by dredging operations, first of all to 17 feet, then to 20 feet, then to 22 feet, then to 24 feet, then to 25 feet, and ultimately to 27 feet at the extremity of the breakwater. The result has been that even at the depth of 27 feet the erosive action of the sea has been so serious that the pier-head is in imminent danger of falling; and large portions of the breakwater, which were founded at 25 feet below low water, are in a state of utter ruin, and have to be entirely renewed. The structure resting upon the rubble mound was practically a monolith of enormous size, because, when the breach in the breakwater took place, and I had to inspect it, I found that an enormous mass of masonry, which was so beautifully constructed that it all held together in one solid block of upwards of six thousand tons, had been moved or tumbled over by the sea, entirely in consequence of the erosion of the rubble mound. It was possible at that time for the divers to work underneath the superstructure, where it had not already fallen, and observe the damage.

It is therefore a question at what depth below low water these works should be founded. We have to rely upon the equation of the exposure to the prevailing wind, and the steepness of the soundings. At Tynemouth the exposure is very long, and the soundings are particularly steep, so that the sea comes in with enormous power, and has not only excavated the rubble from underneath the superstructure, at a depth of 27 feet at low water, but has also removed two tiers of 30-ton blocks which were deposited outside the superstructure on the surface of the rubble mound, in a depth of 25 feet of water, so that the sea has thus been enabled to wash away the smaller stones of the rubble mound. I have come to the conclusion that however heavy you may make the blocks, it is of no use whatever unless the foundation is secure; and the only way, in my opinion, to obtain a secure foundation is to put the foundations in at such a depth as is suitable to the situation in which they have to be placed. It is always wise to bear in mind that when we talk of weight, we generally speak of weight in the air, and not of weight in the water, which is a very different thing. When once the concrete block is tilted or begins to move, owing to some subsidence of the ground on which it rests, the whole condition of things is at once changed, and the sea acquires a power over the block which seems out of all proportion to possibility.

An allusion has been made to parapets. That question was very seriously considered when we proposed the designs for the reconstruction of the Tynemouth breakwater; and I should have much preferred to dispense with the parapet altogether; but in that case, and I daresay in many other cases, it is not a question merely of protecting the promenade; we had to consider the absolute necessity of allowing persons to be on the pier in very exposed weather, for the purpose of saving life; and we also had to provide for the lighting up of the lighthouse at the end of the pier. Therefore we have decided to reconstruct the parapet, although in a much stronger form.

There is nothing so instructive to engineers as the record of failures; and it is these which really teach us our profession. After all, matters of sea work are more or less questions of experiment, based upon the experience of others. I think I am speaking the universal feeling of the meeting when I convey our hearty thanks to MM. de Churruca and Van Gansberghe.

[Paper.]

RECENT IMPROVEMENTS IN THE LIGHTING AND BUOYING, ETC., OF THE SCOTTISH AND ISLE OF MAN COASTS.

By DAVID A. STEVENSON, B.Sc., F.R.S.E., M.Inst.C.E., Engineer to the Commissioners of Northern Lighthouses.

A GLANCE at a chart of Scotland shows that, owing to its exceptionally rugged coast-line, and numerous outlying islands and dangers, the task of lighting and otherwise guarding it effectually for the purposes of navigation, is an interesting and difficult problem for the lighthouse engineer.

Owing to want of funds little was done up till 1854 to light the sounds and kyles on the West Coast, between the outlying islands and the mainland, nor the coasts of the Orkney and Shetland Islands, nor of the western and northern shores of the mainland. The war of 1854, however, made it necessary that something should be done to enable the fleet to navigate the northern seas at least with some degree of safety, and the advantage of lighting the West Coast sounds came also about the same time to be appreciated. Since that period good progress has been made, and in 1875 there were 60 lighthouses, 98 buoys, 49 beacons, and 2 fog-signals on the coast. During the last twenty-five years (since 1875) there have been erected on the coasts under the jurisdiction of the Commissioners of Northern Lighthouses, 16 lighthouses, 21 fog signals, and 28 lighted beacons; and there have been laid down 1 lightship, equipped with a fog-signal, 15 lighted buoys and 9 unlighted buoys, and 12 unlighted beacons have been erected.

The course of a seaman making for and navigating the Scottish coast has thus been much facilitated, though no doubt much remains to be done, for there are still many outlying dangers unguarded, and stretches of coast-line with 50 or even 100 miles between the lights, while the range of our most powerful lights, in weather when they are most required, does not exceed 9 or 10 miles.

The characteristics of the lights on the Scottish coast have also been much improved as regards their distinctive character, which, next to the existence of a light at all, is the most important factor in its usefulness. It has been the policy of the Northern Lighthouse Board to gradually alter the old fixed lights which are liable to be mistaken, or at all events not so readily recognised and identified, and give them a definite character. During the last twenty-five years eight fixed lights on the coast of Scotland have been altered to flashing or occulting lights. The introduction by Messrs. Chance in 1874 of the group-flashing characteristic, proposed by the late Dr. Hopkinson, put into the hands of the lighthouse engineer the power of greatly varying the character of lights, and many lights of this character have been installed on the coast. Further the periods of many of the lights have been shortened as much as possible, consistently with other considerations. Not only has the *number* of the lights been increased and the *characters* improved, but the *powers* of the lights on the Scottish coast have been greatly increased. Thus, in 1875, the most powerful light on the Scottish coast had a power equal to 44,500 candles; now there are several over 100,000 candles, and the Isle of May electric light has a power which we calculate is equal to 3,000,000 candles. The limitation of the duration of flashes to about half a second, and the reduction to a minimum of the number of faces of the apparatus, have long been recognised as leading principles, and acted on in Scotland where consistent with producing the proper characteristic, and a duration of flash of sufficient length. The recent increase in the power of the apparatus has been effected by the use of one or both of the following improvements in lighthouse apparatus, which have been described by Messrs. Chance as "most valuable improvements."

(1) The introduction of hyper-radiant or long focal distance apparatus, proposed by Messrs. Stevenson in 1869, designed and experimented on by them in 1885, and introduced in many lights since that date, both at home and abroad. (2) The introduction of Mr. Charles A. Stevenson's equiangular prisms, which effect a saving of 15 per cent. of the light incident on them at 45°, and 26 per cent. at 40°, and which permit with efficiency of the use of refractors of 80° focal opening in place of only 60° with Fresnel elements. The adoption of flint glass to extend the refracting portion to 80° caused more loss of light than if catadioptric prisms had been used for this portion; indeed, the great divergence from the prisms, and the loss of light due to using flint glass, rendered this portion of the apparatus practically useless as a lighthouse agent.

This increase in the power of the lights has not been effected by increasing the size of the burners employed, as no burner of a larger diameter than six wicks for hyper-radiant, and five wicks for first-order flashing lights, have been introduced, because, owing to want of focal compactness, and the fact that little increase of intensity is obtained, larger burners are considered not to warrant the additional consumption in oil and difficulty of management they entail. Nor has the length of flashes been reduced below two-fifths of a second, as anything less than about half a second is, we consider, too short to give, under practical conditions, full perception.

With the exception of one electric light and five stations where oil gas is employed, four of which are also incandescent, the illuminant used in the Scottish lighthouses is paraffin. The introduction of gas as the illuminant has permitted, at less important stations, of dispensing with the attendance of one of the keepers, reducing the staff to one, who is rung up, should anything go wrong with the light, by an electric automatic alarum.

In the case of lights made by over-sea vessels, and coast lights which are intended to light long stretches of coast, it is necessary that they should be of considerable power, and that they should be constantly attended by keepers to ensure their due exhibition. There are, however, many places on the Scottish coast, as in sounds, lochs, and firths, where lights do not require to be seen at a great distance, and where even the extinction of the light for a time would only cause inconvenience to the sailor, not disaster. In such cases the lights may obviously be of low power, and be unattended continuously by keepers. Lighted beacons and buoys have consequently been introduced at such places on the Scottish coast, to the great advantage of navigation, and at a very small cost. Twenty-three of these beacons and buoys are lighted on Pintsch's system of compressed oil gas, and have given complete satisfaction. They require only to be visited once in six weeks or so. Originally the fixed-light character was all that was available, but, on our suggestion, Messrs. Pintsch introduced a method whereby they show one, two, or three flashes as desired, and this has greatly increased their usefulness, besides reducing the consumption of gas. Twenty-one beacons are lighted with petroleum burned in the Benson-Lee and Lee lamps, in which the wicks are carbon-tipped, and require attention every four or five days, but are an improvement, as regards safety and power, on the Norwegian Trotter-Lindberg system, which was first used in this way. When these lights require to be made flashing, this is produced by revolving shades driven by the current of heated air from the flame.

The buoys in use on the Scottish coast have been increased in size and improved in shape, so as to ride upright even in strong tidal currents, and they are for these reasons more readily seen and picked up by the sailor.

The Otter Rock light-vessel, just launched, will be unattended by a crew, and has been designed to lie in a very exposed situation. The lantern apparatus and glasswork were specially designed to suit the circumstances, and made by Messrs. Chance. The gas fittings are on Messrs. Pintsch's system, and they are the contractors for the work.

Owing to the prevalence of fog and snow showers on the Scottish coast, amounting to between 300 and 400 hours in the year, and lasting occasionally for spells of 36 hours without a break, the question of fog-signalling is very important. Fog-signals minister not only to the safety of navigation, but facilitate the making of regular passages, and hence are greatly appreciated by the sailor and the shipowner. The 24 fog-signals erected on the Scottish coast during the last 25 years have explosive cartridges at two stations and siren fog-horns actuated by compressed air at all the rest. These tonite signals, which give a loud report, were originated by the Elder Brethren of the Trinity House, and are of great value in certain situations. They are only used on the Scottish coast at rock stations, where the siren horn could not be introduced except at a very large cost, as they are not so efficient and much more expensive to maintain than fog-horn signals. For fog-horns the motive power to compress the air used 25 years ago was hot-air engines, which were excellent for the purpose, as they did not require a supply of fresh water, which is not easily obtained at most lighthouse stations ; but, on the other hand, they took about three-quarters of an hour to start, and were costly to keep in repair. We accordingly introduced in 1883 gas engines driven by oil gas, which require little water, and have not the drawbacks of the hot-air engine ; and this having proved successful, we followed it up by the introduction in 1889 of the oil engine then just perfected. Both of these improvements were first used for fog-signalling purposes in Scotland, and the oil engine is now almost invariably so used. Steam engines have been introduced at two stations, in one case because steam boilers were already at the station for the electric-light engine, and in the other because the oil engine had not been introduced, and being a lightship station the choice lay between hot-air and steam engines.

Where oil engines are used, a fog-horn can now be put in operation in about eight minutes, even if there is no air stored, which, however, is done in several cases, so that the signal can be practically instantaneously started. In recent cases the engine power introduced at fog-signal stations has been about 50 H.P., one-third of which is reserve. The working pressure used as a rule is about 30 lbs. per square inch, and about 46 cubic feet of air per second of blowing is expended. The siren used is a modification of Mr. Slight's cylindrical siren. By improving the shape and enlarging the horn and air passages, opening out and properly forming the air-ports of the siren, driving the siren by an air motor, and properly proportioning the storage to the air consumption, we have recently greatly increased the efficiency of the siren fog-horn.

For the purposes of distinction, groups of blasts have been introduced, two, three, and four blasts given in quick succession, and these are still further differentiated by making the blasts of different pitch when necessary. Our endeavour has been to make these blasts as long in duration as possible, consistently with due economy, our view and experience being that a long blast is more effective than a short blast, and that no blast should be less than three seconds, and that five seconds is what should be aimed at. The periods of some recent signals have also been reduced to 1½ minute, though this is, in our opinion, perhaps unnecessarily short, as in most situations a two or even three minutes' period would serve the sailor's requirements, permit of a great reduction of the power, and therefore reduce the expense necessary to produce an effective signal.

In spite of all that has been done to improve our fog signals, they are undoubtedly the weak point in the provision made for leading and guiding the sailor. This is, it is to be feared, inherent in the system of using the air as the carrier of fog-signal warnings, for sound signals are uncertain both as to penetration and location; and the solution of the difficulty will probably ultimately be found in Mr. Charles A. Stevenson's proposal of 1892, of an electric cable or conductor laid down off a coast or danger so as to act on an instrument on board each vessel, and so either warn the sailor of his proximity to it and therefore to a coast or danger, or as a lead along which vessels might sail, keeping, as it were, in touch with the cable.

Although not directly connected with the guarding of the coast, the remoteness of many of the lighthouses on the Scottish coast, one of which is 40 miles from land, one 20, and several about 12, at a very early period caused consideration to be given to the possibility of connecting them with the shore by electric telegraph. The expense involved prohibited the adoption of electric cables; and in 1894 the Commissioners of Northern Lighthouses made an experiment of the wireless system of telegraphy proposed by Mr. Charles A. Stevenson, on the scale and distance that was required for one of the stations in the Northern Lighthouses Service. This experiment, which was carried out with the assistance of the General Post Office officials in Edinburgh, proved quite successful; but the Board of Trade declined to sanction its adoption on the ground that flag signals were sufficient. Since then many other similar or cognate proposals have been suggested, but nothing practical has yet been done.

[Paper.]

RECENT IMPROVEMENTS IN THE LIGHTING AND BUOYING OF THE COASTS OF FRANCE.

By Baron Quinette de Rochemont, Inspecteur Général des Ponts et Chaussées, Directeur du Service des Phares, M.Inst.C.E.

Introduction.

The Department of Lighthouses and Beacons in France, under the able direction of the late and regretted M. Bourdelles, has introduced many improvements in the lighting and buoying of coasts. This eminent engineer gave much attention to all the different branches of the service, and in most of them he made improvements, some of which, of considerable importance, have since been adopted in other countries. M. Ribière, ingénieur en chef des Ponts et Chaussées, and MM. de Joly and Blondel, ingénieurs des Ponts et Chaussées, on the staff of the Central Department of Lighthouses and Beacons, have been valuable assistants to Inspecteur Général Bourdelles; and credit is due to them for an important share in the results that have been obtained.

One of the chief improvements has been the adoption of *feux-éclairs*, or lightning-lights. With this new device the maximum efficiency of the illuminating apparatus is obtained; whether the illuminant be oil or electricity, it has given rise to quite a series of new types of appliances used in connection therewith. Again, the luminous efficiency of the optical apparatus has been increased by improving the focal precision, and by keeping the characteristic or effective divergence within narrow limits. The generating stations for electric lighthouses, built until quite recently on old-fashioned lines, have been brought up to date with all modern improvements. The adoption of incandescent burners for compressed gas or petroleum vapour has been a great step in advance. Not only has the intensity of the light been increased, but a light with a wick and ordinary mineral oil can now be made to burn continuously night and day, for three months, with only occasional examination at long intervals of time. These permanent lights can have all the characteristics of superintended occulting or flashing lights. The adoption of permanent lights has enabled points of secondary importance to be lighted under economical conditions, and has thus efficiently filled a gap in the system of maritime illumination. Other permanent lights, in the form of illuminated buoys fed with oil-gas, have been adopted on an extensive scale, either to increase the protection at dangerous points and as substitutes for certain lightships, or for lighting winding and shifting channels; also for supplementing the indications afforded by leading lights or sector lights, or for pointing out the position of works in construction at the entrance of harbours.

Investigations have been made to determine in each particular case the shape, the stability, and the method of mooring suitable for these buoys; and these have led to the adoption of certain types which have proved satisfactory in practice. Considerable improvements have also been effected in the construction of lightships, for they are now shaped, and the weight distributed so as to greatly increase their stability. In place, moreover, of the old catoptric appliances, powerful lenticular apparatus, with incandescent gas as an illuminant, are employed instead. This apparatus is in the form of a compound pendulum with very slow oscillations, so that it is almost unaffected by the rolling and pitching of the vessel. Experiments have been made, under the most varied conditions, with a view to determine the best system of compressed-air sounding signals. These experiments have led to the adoption of definite types, and they have demonstrated that an air-pressure of about two kilogrammes (28 lbs. per square inch) is the most suitable for sirens. These experiments have given satisfactory results which have established the contrivances adopted for causing the instantaneous action of sound in signals, situated at great distances from the lighthouse containing the engines and the custodians.

Attention has also been paid to the various questions relating to the utilisation of lighthouses for nautical purposes. Systematic observations have been carried out on atmospheric refraction near the horizon, and its effect upon the geographical range of lighthouses; and observations have also been made upon the depression of the sea horizon. Investigations as to the precision of leading lights have also been taken up again, and have led to practical modifications of the old rules governing their establishment. Important innovations have been introduced in the construction of isolated works at sea, and especially in beacon-towers. The Lighthouse Department, moreover, responsible for the erection of many remarkable works, has recently built several towers of great height, which are of interest for various reasons. The Coubre electric lighthouse is a specimen of an economical high tower; the Eckmühl lighthouse is one of the finest works of its kind; and the lighthouse now in course of construction on Vierge Island will be the highest in the world, as its height when finished will be 75 metres (246 feet).

Increase in the Illuminating Power of Lighthouses.

The illuminating power of lighthouses has been increased by (1) increasing the intrinsic brightness of the luminous source; (2) greater perfection in the manufacture of the optical apparatus; (3) reducing the number of lenticular panels, and increasing their surface and power by employing lightning-lights.

The brightness of the beam from a lenticular panel is proportionate to the intrinsic brightness of the luminous source at the burner, and not to the luminous intensity. The mean intrinsic brightness of flames produced by oil lamps increases only to a slight extent with the size of the flames; consequently, the light efficiency diminishes, whilst the expense is greater, and the service more irksome. The illuminating power of lighthouses can, therefore, only be improved to a slight extent by increasing the number of wicks.

The adoption of Aüer incandescent burners for compressed gas and petroleum vapour has enabled a great improvement to be effected in practice. Incandescent lighting by acetylene gas will probably give even better results, at any rate as regards light efficiency; acetylene lighting, however, is only at present in its experimental stage. The trials carried out at the central lighthouse works have been sufficiently thorough to enable this method of lighting to be shortly applied to the Chassiron Lighthouse in the Charente-Inférieure. Electric light, which has a far greater intrinsic brightness than incandescent light, has only been adopted in the thirteen most important lighthouses protecting the principal headlands, on account of the great expense it entails.

The intrinsic brightness, in a horizontal direction, of various systems of lighting employed in lighthouses is as follows, expressed in carcels per square centimetre of the mean horizontal focal plane of the luminous source :

Burner with mineral oil and 1 wick	0·35 carcels*
" " " " 2 wicks	0·50 "
" " " " 3 "	0·80 "
" " " " 4 "	0·95 "
" " " " 5 "	1·10 "
" " " " 6 "	1·18 "
Incandescent lighting with compressed oil gas	2·00 "
" " " petroleum vapour...	2·50 "
" " " acetylene	4·00 "
Crater of the electric arc	900·00 "

* 1 carcel = 9·5 candles.

The luminous efficiency of the optical apparatus has been considerably increased within recent years. The efficiency depends on two things, namely, focal precision and the characteristic or effective divergence. New methods of measuring these have been applied, not only at the works, but also for testing purposes. It has therefore been possible to keep allowances for errors within narrower limits than heretofore. In this manner, and by renewing or improving their machinery or plant, French manufacturers have arrived at a very high standard of excellence in the manufacture of optical apparatus. Even with such sources of light as the electric arc or the Aüer burners, it has been possible to obtain compact and regular luminous beams.

Experience has shown that there is no advantage in prolonging the duration of the flash beyond $\frac{1}{10}$ second, which is about the minimum time required for full perception, and that an average interval of five seconds between the flashes is sufficient to enable seamen to get their bearings. By reducing the duration of the flashes as far as possible to the time actually required for the full perception of their luminous intensity, it has been possible to construct the optical apparatus with a small number of lenses of large surface, and consequently of great power. This new optical apparatus is much less bulky and cheaper than the corresponding apparatus of the old types. The period of revolution of this apparatus is consequently rapid, occupying only from 5 to 25 seconds. This unprecedented speed, especially for first-order lighthouses, is obtained by means of simple mechanical contrivances and light clockwork mechanism.

In the case of lights with flashes at regular intervals, the optical apparatus has even been made with a single set of lenses, covering a semicircle in plan, the hinder half of the rays being thrown back into the luminous beam by a reflector. This arrangement utilises two-thirds of the total light, and gives an efficiency that had never been attained in flash-lights; but, owing to the velocity of rotation required, it is necessary to give the beam a large horizontal divergence. With two sets of lenses, each occupying a semicircle, half the total light can be utilised; and this type of apparatus is suitable for lenses with a long focal distance.

The new type of light, with flashes at regular intervals, does not require an apparatus with four sets of lenses, except for electric lighthouses with a very small luminous source, or for lighthouses illuminated with incandescent gas and petroleum vapour. Nevertheless, as a precautionary measure, the first experiments in France were carried out with optical apparatus with four panels. Similar types have been designed for group-flashing lights. The lightning-lights are exceedingly powerful, and within recent years they have been extensively adopted. They are now too well known to require that their advantages should be pointed out.

The table on the opposite page shows the increase that has taken place in the illuminating power of lighthouses.

Although the increase of the intrinsic brightness of the luminous source exercises the principal influence in increasing the illuminating power of lighthouses, it is nevertheless necessary to consider to some extent the dimensions of that source. In fact, these dimensions, for a given focal distance, determine the divergence of the luminous beams and, consequently, the duration of the flashes. The greater the luminous source for the same intrinsic brightness, the greater may the focal distance be, or the less may be the number of panels; and the greater also is the luminous efficiency for the same focal precision. We may, therefore, expect further improvements in this direction, resulting in increased luminous power by means of larger incandescent mantles than those, 0·03 metre (1·18 inch) in diameter, hitherto in use. The Lighthouse Department intends shortly to introduce mantles 0·045 metre (1·77 inch) in diameter, with suitable burners for incandescent lighting, either by petroleum vapour or acetylene.

ELECTRIC LIGHTS.

The illuminating power of electric lighthouses is so great that there is no occasion to seek to increase it; nevertheless, some important improvements have been made in this method of lighting. In lighthouses with a single set of optical apparatus, such as those of La Hève and of the island of Yeu, there are three powers of light, produced by currents of 25, 50, and 100 ampères at 45 volts. In lighthouses with a double set of optical apparatus, such as at Eckmühl and Créac'h, there are only two powers, produced by currents of 25 and 50 ampères each. The power of 25 ampères, with which

Lighthouses.	Characteristics.	Luminous Source.	Date.	Focal Distance.	Width of the panels in terms of the circumference.	Intensity of Light.	Remarks.
LIGHTHOUSES ILLUMINATED WITH OIL.							
				M. Inches.		Carcels.*	
Île de Batz	White, prolonged flashes, regular . . 1 m.	Burner, 5 wicks	1873	0.92 (36·22)	$\frac{1}{8}$	5,132	Lower and upper mirrors.
Ailly . .	,, ,, ,, . . 1 m.	,, ,,	1873	0·92 (36·22)	$\frac{1}{8}$	6,199	Catadioptric rings.
Contis .	,, ,, ,, . . 30 s.	,, ,,	1873	0·92 (36·22)	$\frac{1}{16}$	4,085	,, ,,
Chassiron	,, ,, ,, . . 10 s.	,, 6 wicks	1891	0·92 (36·22)	$\frac{1}{8}$	7,000	,, ,,
Antifer .	,, ,, ,, . . 20 s.	,, ,,	1894	0·33 (12·99)	$\frac{1}{6}$	16,000 to 22,000	Hyper-radiant apparatus.
LIGHTHOUSES ILLUMINATED BY INCANDESCENCE.							
Chassiron	White, prolonged flashes, regular . . 10 s.	Incandescent gas	1895	0·92 (36·22)	$\frac{1}{8}$	18,000	Old optical apparatus, first order.
Île de Sein	White lightning-light, 4 group-flashes 25 s.	,, ,,	1897	0·92 (36·22)	$\frac{1}{8}$	25,000	,, ,, ,,
Ailly . .	,, ,, 3 ,, 20 s.	,, ,,	1899	0·70 (27.56)	$\frac{1}{5}$	50,000	Double set of new optical apparatus.
Île de Batz	,, ,, 4 ,, 25 s.	,, petroleum	1900	0·92 (36·22)	$\frac{1}{8}$	25,000	Old optical apparatus, first order.
Île Vierge.	,, ,, regular . . . 10 s.	,, ,,	1901	0·70 (27·56)	$\frac{1}{4}$	60,000	Double set of new optical apparatus.
Chassiron.	White prolonged flashes, regular . . 10 s.	,, acetylene	1902	0·92 (36·22)	$\frac{1}{8}$	36,000	Old optical apparatus, first order.
LIGHTHOUSES ILLUMINATED BY ELECTRICITY.							
Calais . .	White, prolonged flashes, 4 group-flashes 15 s.	Electric arc. .	1883	0·30 (11·81)	$\frac{1}{24}$	90,000	
Créac'h .	,, ,, 2 ,, 10 s.	,, . .	1888	0·30 (11·81)	$\frac{1}{12}$	350,000 to 650,000	
La Hève .	White, lightning-light, regular . . 5 s.	,, . .	1893	0·30 (11·81)	$\frac{1}{4}$	1,000,000 to 2,000,000	
Griz-Nez .	,, ,, ,, . . 5 s.	,, . .	1899	0·30 (11·81)	$\frac{1}{4}$	1,500,000 to 3,200,000	Double set of optical apparatus.
Créac'h .	,, ,, 2 group-flashes 10 s.	,, . .	1901	0·30 (11·81)	$\frac{1}{4}$	,,	,, ,, ,,

* 1 carcel = 9·5 candles.

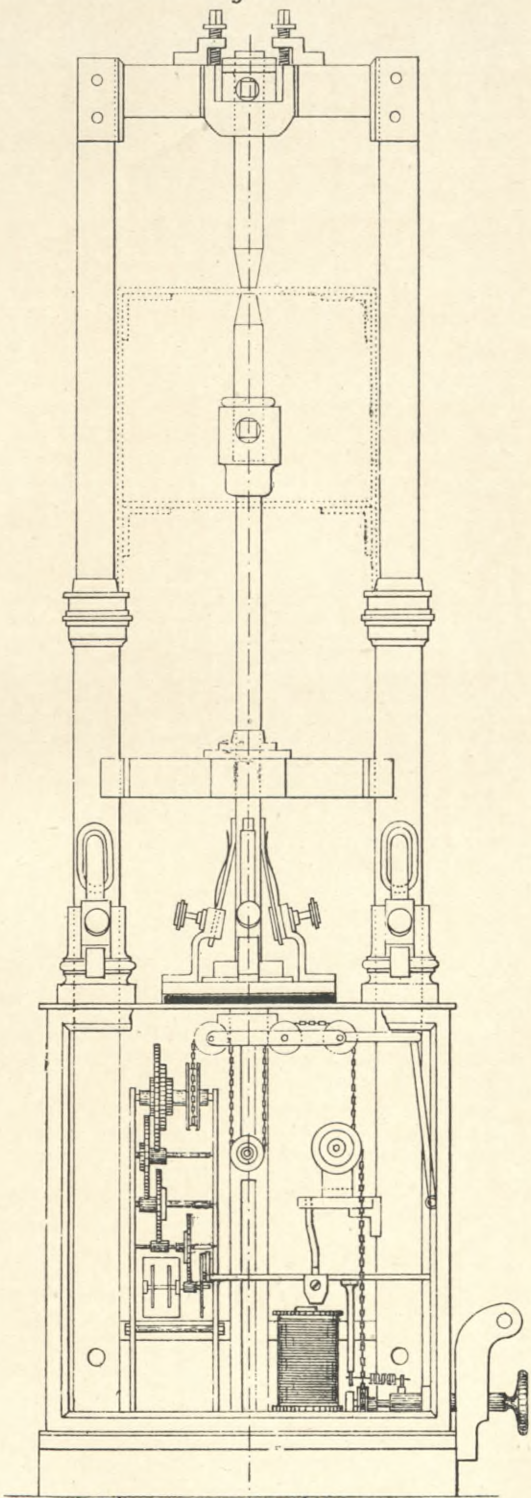
the efficiency of the optical apparatus is comparatively feeble, owing to the extreme smallness of the light, is only used during very clear weather. With a double set of optical apparatus, the two arcs of 50 ampères are almost in constant use, and absorb the whole power of the two dynamos which have hitherto been employed.

In order to have one machine in reserve, and also to be able to couple up both machines and obtain two arcs of 100 ampères for use in thick weather, a new type of diphase alternator of 5·5 kilowatts has recently been designed and tried. This alternator consists of an eight-pole field magnet formed of thin iron sheets, surrounded by the exciting coils ; of an armature also formed of thin iron sheets ; of three rings and brushes for collecting the current ; and of a continuous-current exciting dynamo which is carried on one of the bearings. The armature is provided with 64 grooves, containing eight wires of 3·3mm. (0·13 inch) diameter, arranged in groups of four, in parallel. The coiling is arranged in two layers formed by two superposed windings with a phase difference of $\frac{1}{4}$ period, each containing all the spirals in series. The two circuits, thus closed, terminate in three insulated bronze rings, against which three brushes rub, capable of receiving a current of 75 ampères without heating or emitting sparks. The intermediate ring constitutes a pole in common. An electro-motive force of at least 85 volts is obtained on these circuits when normally excited in open circuit, the voltage being automatically reduced to about 45 volts when there is a 50-ampère current at the regulators. The heating, when working with a normal load, does not exceed 40° Centigrade (104° Fahr.) above the temperature of the surrounding air. If one of the lamps is put out of use, mutual reaction between the two circuits does not cause the current in the other lamp to vary more than 10 per cent. The efficiency, when working with a full load, is not less than 80 per cent. The exciter is a small Gramme machine with a toothed armature fixed to the same shaft, and self-exciting when shunt wound. It is easily self-excited ; and by means of a rheostat the electro-motive force of the alternator can be easily controlled.

The old pattern of electric arc regulator, which had only one rod for conveying the current, caused the carbons to burn unsymmetrically and to produce uneven shadows. To remedy this, a much lighter and more exact regulator with two symmetrical rods has been designed. By employing aluminium, the weight, which formerly exceeded 40 kilogrammes (88 lbs), has been reduced by more than 50 per cent.

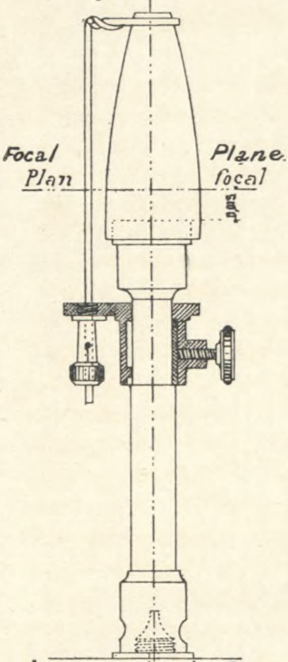
The new regulator (Fig. 1) consists of a box with two glazed sides, which contains the mechanism. Three guiding uprights are fixed to the box ; the central is isolated, and the two outer ones are connected together by a cross-piece. These uprights are slit vertically, and have brushes which convey the current to the sliding rods. Three bronze rods slide up and down these uprights ; the two outer rods are connected at each extremity by a cross-piece ; the upper cross-piece has a carbon holder which is designed so as to enable the upper carbon to be fixed in position ; the central rod carries an ordinary carbon holder. Clockwork mechanism with a regulating electro-magnet moves the rods simultaneously, and controls the movement of the carbons so that they are displaced at the same rate as they are burnt. The light can be shifted up and down ; and the lower carbon can be brought into contact with the upper one at the moment of lighting.

Fig. I.



Electric Regulator.
Régulateur électrique

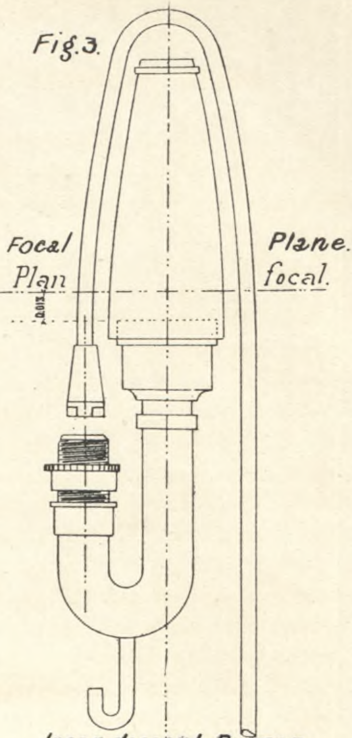
Fig. 2.



Incandescent Burner for oil Gas.

Brûleur à incandescence par le gaz d'huile.

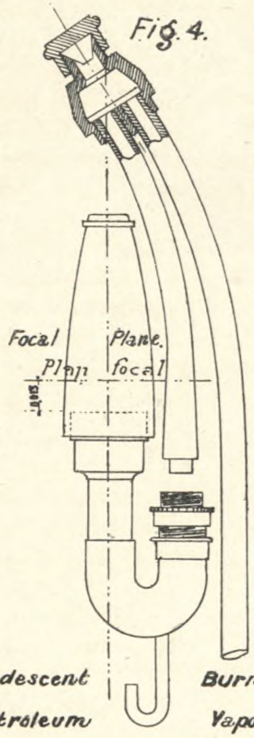
Fig. 3.



Incandescent Burner for Petroleum Vapour

Brûleur à incandescence par la vapeur de pétrole.

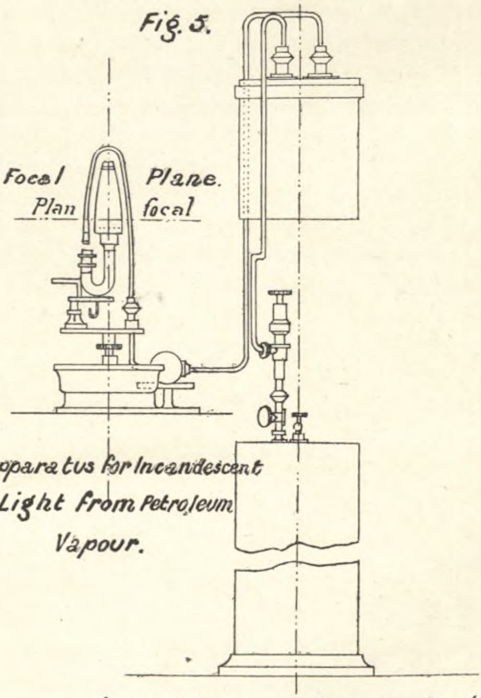
Fig. 4.



Incandescent Burner for Petroleum Vapour.

Brûleur à incandescence par la vapeur de pétrole.

Fig. 5.



Apparatus for Incandescent Light from Petroleum Vapour.

Incandescence par la vapeur de pétrole.

Ensemble.

It is by improvements such as have been described that it is possible to obtain that greater precision of the optical apparatus which plays such an important part in electric illumination.

Incandescent Lighting with Compressed Gas or Petroleum Vapour.

The light given by Aüer mantles, heated by gas to incandescence, has such great intrinsic brightness that the Lighthouse Department has been induced to try this system of illumination.

Incandescence with low-pressure gas only gives a comparatively feeble intrinsic brightness. Compressed gas must be used in order to obtain a greater intrinsic brightness than that afforded by the largest petroleum burners in use. With compressed gas, the quantity of gas supplied to the mantle and the rate of combustion vary in proportion to the pressure ; whilst the dimensions of the incandescent light remain unaltered. The temperature of the mantle and its intrinsic brightness are, therefore, gradually increased. To overcome the objectionable condensation which occurs when coal gas is used, even at low pressures, the Pintsch gas, which is already in use for lighting buoys, has been adopted. This gas can bear a pressure of 10 or 12 kilogrammes (140 to 168 lbs.) without condensation, so that it can be stored in small portable reservoirs.

The burner (Fig. 2) employed consists of a vertical tube, with a Bunsen burner and Aüer mantle at the top ; an ejector for the compressed gas is placed at the bottom of the tube. For proper combustion, the volume of air supplied to the mantle must be eight times that of the gas. The pressure of the gas is 0·16 kilogramme per square centimetre (2·24 lbs. per square inch) ; the rate of consumption of gas is 160 litres (5·65 cubic feet) per hour, and 4·5 litres (274·6 cubic inches) per hour per carcel. A regulator supplies the gas at constant pressure, so that a luminous source of almost constant intensity can be obtained with occasional instead of constant supervision. This system has been adopted for several first-order lighthouses (Chassiron, Île de Sein, Île de Groix), for the Ar-men lighthouse out at sea, and for the Ailly lighthouse.

The necessity of building works for supplying the oil gas has limited the application of incandescent gas lighting to a few important lights. The Lighthouse Department, therefore, has endeavoured, with success, to obtain the same advantages, for a slight outlay, by substituting petroleum vapour for incandescent lighting. The burners employed are all made on the same principle, but their arrangements differ slightly, according to the type of lighting apparatus for which they are intended. This principle consists in injecting the liquid petroleum into a vaporiser heated by the mantle ; the vapour then passes into the Bunsen burner of the mantle, after mixing with the air required for combustion. In starting, the vaporiser is heated by a spirit flame to the required temperature.

If the type of optical apparatus permit, the vaporiser is made in the form of an inverted U (Fig. 3), with its extremities placed as near as possible to the mantle. When the optical apparatus does not permit of the above arrangement for the vaporiser, or where a fixed burner is employed, the optical apparatus being alone movable, the tube conveying the petroleum is placed against the vaporiser (Fig. 4). The two tubes thus cast a single shadow, which can be thrown into the dark arc of lightning-lights with group-flashes, or into the landward arc in the case of the old type of apparatus. The adoption of larger mantles and of vaporisers with flattened tubes, now on trial, will tend in future to limit the use of burners of the type represented on Fig. 4. These burners only require the addition of a petroleum reservoir of a minimum capacity of 4 litres (244 cubic inches), which is connected with another reservoir of at least double the capacity, filled with air at a pressure of 6 kilogrammes (84 lbs.) (Fig. 5). A regulator maintains the pressure of the air upon the petroleum to at least 2 kilogrammes (28 lbs.). The consumption of petroleum is as low as 4 grammes (0·147 oz.) per hour per carcel of light intensity in the mantle. A consumption of 5 grammes (0·175 oz.), however, is assumed in practice, and this is much lower than that of any lamp hitherto employed. The total rate of consumption per hour is therefore 175 grammes (6·172 ozs.).

Petroleum vapour is employed as an illuminant for the lighthouses of Four (Finistère), of Roches Douvres, and of the Grand Charpentier, all of which are situated out at sea; for the leading lights of Graves, Saint Georges, Trézien and Saint Mathieu, and for the flash-lights of the island of Batz, of Kermorvan, of Poulains, and of Camarat. This illuminant will also be adopted for the lighthouses of Cape Béar, of the Mont Saint Clair, and of the Île Vierge, now in course of construction.

Incandescent gas lighting, when no special gasworks are required, is not much more expensive than lighting with a three-wick burner; and even when special works are necessary it is more economical than a five-wick burner. The annual expenditure for gas lighting does not exceed 1,800 francs (£72) with gasworks, or 800 francs (£32) without works; for petroleum vapour lighting it amounts to 650 francs (£26). These figures show at a glance the advantage, from an economical point of view, of the system of incandescent lighting.

Permanent Lights.

The Lighthouse Department has taken steps to protect navigation by illuminating the beacon towers and shoals out at sea, where the erection of ordinary lighthouses is precluded on account of the expense. This has been carried out by means of small single-wick lights with ordinary mineral oil, which can burn for several months without having to be attended to. The wicks used for this purpose are specially prepared, the surface of the wick being evenly coated with a thin layer of carbonised tar, the operation being termed *croûtage*, or caking. The luminous intensity of these lights, which is equivalent at the outset to two carcels, diminishes gradually, till, at the end of two months, it is only equal to one carcel. Excellent results are obtained; but, like all unattended lights, they afford less security to navigation than the ordinary ones. The total consumption of oil, including the waste from the overflow, is from 35 to 40 grammes (1·234 to 1·411 oz.) per hour. This system of permanent lights was first applied to a number of fixed lights. It was subsequently adopted for illuminating the pier-heads of Port Tudy (Île de Groix), of Palais (Belle-Île), of Turballe, of Cette, etc., which are inaccessible during rough weather; and for illuminating the beacon-towers of Morées (situated near the approaches of St. Nazaire), of the Trois Pierres (entrance of Lorient), of the Vinotière (near Brest), and of the Vieux-Moines; also for the lighthouses of Haut-Banc-du-Nord (Île de Ré), and of l'Île Harbour (Bay of St. Brieuc), which are situated out at sea. This system has been applied to such an extent that it was necessary to give these lights all the characteristics of attended lights. This has been effected by adopting the system of flotation in a mercury bath, employed with lightning-lights, which enables the apparatus to be easily revolved.

With light optical apparatus, the power required for the rotation, at ordinary speed, does not exceed 1,250 grammes centimetres (0·09 ft. lb.). Consequently, a battery, which has only to be recharged at long intervals, suffices to rotate the apparatus. This battery operates a Gramme ring which revolves between the poles of two permanent magnets; the Gramme ring, in its turn, rotates a central vertical shaft connected with the optical apparatus. The average velocity of rotation is only one revolution in ten seconds; and owing to the very slow speed, it is necessary to employ a large number of very fine wire-coils of great electrical resistance. The apparatus has, consequently, very little stability in working; and to increase this, the armature is provided with a series of copper rings, in which Foucault currents are set up, having a strength approximately proportionate to the speed, which act as a sort of electro-magnetic brake. In this way the resistance increases automatically with the speed; and any accidental slowing down is avoided, as immediately there is a tendency to reduce speed, the resistance is diminished to a corresponding extent. The battery is composed of four or five Labaude and Chaperon cells of 600 ampère-hours capacity, coupled in series. These cells have a fairly constant electro-motive force of 0·80 volt at the outset; after a few hours the voltage falls to 0·65 volt at the terminals, and to 0·60 volt at the end of the discharge. The resistance is 0·04 ohm at the commencement of the discharge, and about double that amount at the end. The capacity is at least 300 watt-hours, with an electro-motive force of 0·65 volt. Assuming a rate of consumption of about 0·100 watt-hour per cell (0·150 a. × 0·65 v.), the discharge will continue for 3,000 hours, or 125 days. As the electro-motive force at the terminals is reduced by about 20 per cent. from the commencement to the end of the discharge, care must be taken to recharge each cell in rotation, and at stated intervals. This keeps the electromotive force fairly constant; and the speed of the apparatus is only affected by variations in the passive resistance. In fact, the stability in actual working is such that there is only a variation of three seconds more or less in the ten seconds arranged for each revolution of the optical apparatus.

This arrangement has been adopted to characterise occulting lights, such as those of the Roche Mengam (Goulet de Brest), and of Men-Hir (near Penmarc'h); or lightning-lights with regular flashes, such as those of the Île Saint Marcouf; or lightning-lights with two or three group-flashes, such as those on the jetty of the commercial port of Cherbourg; and those of Ville-es-Marten (groups of two flashes), of the Horaine de Bréhat, of Walde, and of Corn-Carhai (groups of three flashes).

The luminous power of permanent lights averages 100 carcels for regular lightning-lights, from 85 to 60 carcels for lights with groups of two or three flashes, and 8 carcels for fixed lights.

Lightships.

The Lighthouse Department has within recent years inaugurated a new departure in lightship construction. In the first place, it was found that the period of oscillation of the waves, which materially affects the stability of a lightship, is fairly constant at each site of anchorage. Endeavours were consequently made to diminish the amplitude of oscillation of lightships—(1) by eliminating synchronism between the period of oscillation of the lightship and that of the waves acting upon it; (2) by reducing the rolling produced by the waves by the addition of side keels to the vessel. This was done, in 1890 and 1891, on the "Dyck" and "Ruytingen" lightships, of 290 and 338 tons displacement respectively. The period of roll of these lightships has been prolonged to four seconds; whereas the period of oscillation of the waves at the site is two and a half seconds. The period of four seconds has been arrived at by reducing the leverage of the metacentre in cross-section to less than 0·8 metre (2·624 feet), and also by increasing the transverse moment of inertia by placing pig-iron ballast as far distant as possible from the longitudinal axis of the ship. The reduction or rapid cessation of the oscillations is produced by adding three keels to the vessel, the central keel being 1 metre (3·28 feet) deep, and the side keels 0·75 metre (2·46 feet) deep. The increase of stability thereby obtained is very marked. It has been still further increased by designing the other parts of the ship so that the waves have less effect upon it, and so that a greater force is required to incline the ship to a given angle than was necessary with former types of lightships. This has been obtained by building recent lightships with a reduced section at the water-line, and with a lower centre of gravity, the displacement and periods of roll remaining the same. The draught of the vessels has consequently been very much increased; and the ballast consists of pieces of cast-iron attached to the central keel outside the vessel.

These arrangements have been tried on two new lightships, the "Talais" and "Snouw," which, being less exposed, could be made smaller than the "Ruytingen" lightship, with 100 tons and 130 tons displacement respectively. The trials made with these vessels confirmed all expectations as to their stability, but they also showed that the "Snouw" was too small to withstand the waves of the open sea. Heavy waves sweep its deck; and although they do not affect the vessel's stability, they render the work of the crew very trying. It is proposed, however, to remedy this by lengthening the hull.

The information afforded by these various trials and experiments has been utilised for the design of the lightship which is to be moored on the Sandettié. These designs have been made by the Central Lighthouse Department, assisted by M. Terré, ingénieur en chef de la marine (*see Plate*). A series of observations taken during three consecutive months (July 11 to October 31, 1900), at the site proposed for the new lightship, show that the motion of the sea at this point is precisely similar to that at the anchorage of the "Ruytingen" lightship, and that the half-period of oscillation of heavy waves is about two and a half seconds. The principal dimensions of the "Ruytingen" lightship, which has afforded satisfactory results, have therefore been taken as a basis, and modified, where necessary, in accordance with the results of the observations and experiments referred to above. The main dimensions of the vessel have, consequently, been fixed as follows :—

	Metres.	Feet. Inches.
Length over all	35·00	(114 10)
Width at the water-line	6.24	(20 5)
Depth from deck to bottom of hold, at centre	5·10	(16 8½)
Depth from water-line to bottom of hold, at centre ...	3·60	(11 9½)
Projection of the keel and false keel in the middle ...	1·00	(3 3)
Mean draught, when loaded	4.60	(15 1)
Depth of side keels, at centre	0·80	(2 7½)
Displacement	342 tons.	

The metacentric leverage transversely is 0·393 metre (1·29 feet), and 30·36 metres (99·58 feet) longitudinally. The hull is divided into six compartments by five water-tight partitions across the ship. The two compartments at either end are separated into an upper and a lower chamber by a wooden deck. The compressed-air reservoirs for the sounding signal and the gas reservoir for illumination are placed in the third compartment from the bow; the boilers, the machinery for the sounding signal, and the coal-bunkers are in the fourth compartment. The crew's quarters are in the second compartment, and the officers' quarters are in the fifth. The latter contains water cisterns of a capacity of 10 *tonneaux* (2,200 gallons). The end compartments, fore and aft, are used as store rooms for sails and ropes. The captain's cabin, the chamber for the sounding signal, and the cook's galley are placed on deck amidships, where the gangways leading down to the four central compartments are also situated. The lantern is carried on a hollow iron mast of 0·75 metre (2·46 feet) internal diameter; access is provided by two doors in the mast, one on deck level and another in the machinery room. The sails consist of a jib and mainsail, the latter hoisted along an iron upright parallel to the mast, and of a jigger attached to a special mast. There are four anchors: a mushroom anchor weighing 2,000 kilogrammes (4,400 lbs.), two anchors of 700 kilogrammes (1,540 lbs.) for the catheads, and a cast-iron sinker of 120 kilogrammes (264 lbs.).

The mooring cables are 0·042 metre (1·654 inch) in diameter and 300 metres (984 feet) long. Two steel hawse-holes are provided in the bulwarks for the sheet anchors. Another cylindrical hawse-hole, in the centre of the bow, connected with the stem slightly above the water-line when loaded, is provided for mooring the ship. The lightship has two small life-boats, 6 metres (19·68 feet) and 5·75 metres (18·86 feet) long respectively, provided with air chambers.

The illuminating portion consists of a swinging optical apparatus for a lightning-light, giving out white flashes at regular intervals of five seconds. The optical apparatus, which has four panels of 0·25 metre (9·84 inches) focal distance, is provided at the lower part with a rod carrying a counterweight. This rod is fixed by means of a *Cardan* joint, below the apparatus, in the centre of a horizontal ring rolling on steel ball-bearings and operated by the rotating machine. Another counterweight is placed at the top of the apparatus. This apparatus weighs 700 kilogrammes (1,540 lbs.), and is so designed that its centre of gravity is 0·015 metre (0·591 inch) below the point of suspension. Under these conditions, the period of a single oscillation of the apparatus is about eight seconds. The difference between this and a half-period of the roll of the ship is such that the divergence of the apparatus from the vertical is less than five to six degrees, and the illumination is not affected thereby. The illuminant for incandescent lighting is compressed oil gas. It is conveyed through a pipe running up the mast, and when it reaches the top it passes through a mercury joint into a small tube which turns exactly at the same rate as the apparatus, by means of a train of wheels operated by the rotating machine. This small tube is connected by a rubber pipe to the lower rod of the apparatus, which has a hole running up the centre for the passage of the gas to the burner. The illuminating power is 3,500 carcels. The gas is stored in three reservoirs, which are tested at a pressure of 8 kilogrammes (112 lbs.); two of the reservoirs have a capacity of 6,300 cubic metres (8,240 cubic yards), and the third a capacity of 5,200 cubic metres (6,801 cubic yards).

In addition to the illuminating apparatus, the lightship has to be provided with plant for the sounding signal. This comprises two boilers with distilling plant, self-condensers, and air-compressors; and a single siren worked by compressed air, with reservoirs and accessories. The boilers and condensers are also used for working the steam windlass on board. These boilers are of the type adopted for the 50-H.P. engines of scouting or despatch steam launches of the French Navy; they have an internal fire-box, a direct flame, with forced draught by means of a steam jet into the flue, and a distilling boiler tube. The self-condensers have a single cylinder steam-engine which operates an air-pump, two feed-pumps, the pumps for the recuperator of distilled water, and the centrifugal pump for maintaining the circulation of the water. The air-compressing plant consists of a steam-engine working a compressing pump with two pistons, and a pump for maintaining the circulation of the sea water. The compressing pumps are designed to work, at will, either at a pressure of 15 kilogrammes (210 lbs.) or at 2 kilogrammes (28 lbs.).

The sounding signal is a single-note siren, requiring 400 litres (14·12 cubic feet) of air per second; the pitch of the note corresponds to 330 vibrations per second. The rotating machine causes the siren to emit a sound of three seconds' duration, alternating every ninety seconds with a series of three notes, each of three seconds' duration, with intervals of three seconds between each note. There are two reservoirs for storing the necessary air for starting the apparatus instantaneously; they have each a capacity of 8,150 cubic metres (10,660 cubic yards) and are tested at a pressure of 15 kilogrammes (210 lbs.).

The Sandettié lightship and accessories will cost 340,000 francs (£13,600). This estimate is arrived at as follows:—

	Francs.	£
Hull, including cable and anchor gear, etc.	225,000	(9,000)
Optical apparatus and gas reservoirs	33,000	(1,320)
Boilers and self-condensers	30,000	(1,200)
Sounding signal apparatus and air reservoirs.	22,000	(880)
Air compressors	17,000	(680)
Erection, and various items	13,000	(520)

The crew will consist of a captain and a mate, who will succeed one another on board every alternate fortnight; twelve seamen, eight of whom will be on board and four on land, so that each seaman will in turn spend a month on board and a fortnight on land; two mechanics to attend to the engines, who will succeed one another on board in rotation every fifteen days.

Beacon-Towers in Concrete, and in Neat Cement.

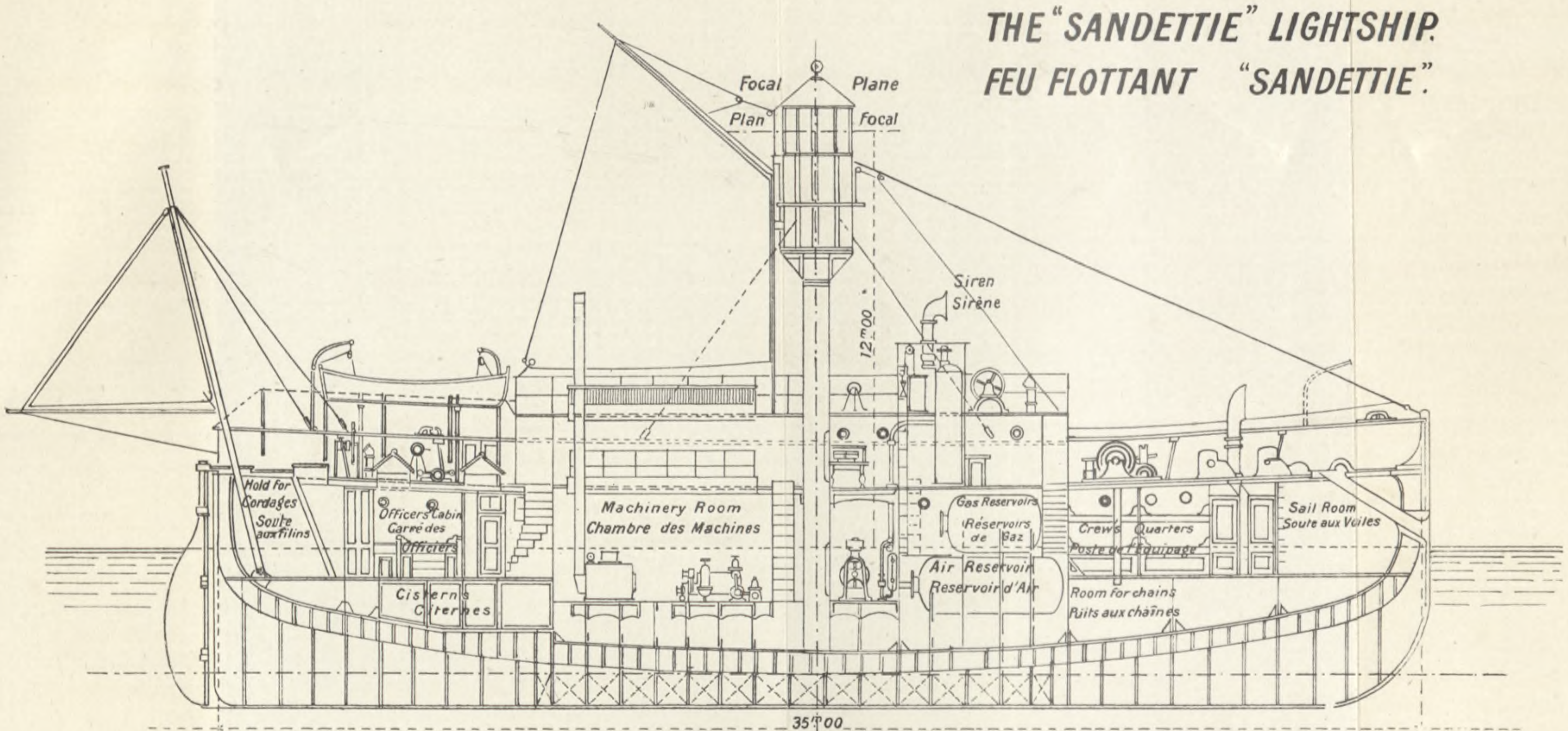
Apart from the action of the wind, towers which are very exposed are shaken by heavy waves. This gives rise to the vibration and noise which are produced by any violent impact. It is quite logical to consider these as the effect of the impact of waves upon the tower, because an appreciable part of the kinetic energy of the waves has, in a very short interval of time, been absorbed and converted into molecular work in the tower. The theory of impact tells us, and practice confirms this, that the resistance of a body to a shock depends principally upon its total mass, and also that the more homogeneous a body is, the greater is its resistance. Looking at the question from this point of view, in which the essential factor of resistance is the whole mass of the tower, we find it advisable to build the latter in the form of a monolith.

Thus, instead of building the most recent French lighthouses at sea with ashlar masonry, the method adopted has been to employ small stones set in Portland cement, with a facing of small pick-dressed stones. Similarly, beacon-towers which were formerly built with ashlar masonry, and subsequently with small stone and ordinary masonry, are now constructed of concrete or of neat cement deposited within framing. This simplified method of construction is economical and rapid; and, moreover, it increases the resistance of the work to the principal stresses to which it is subjected. When it is advisable or necessary to accelerate the work of construction, the expense can even be reduced by employing neat cement. The framing, within which the concrete is deposited when the work is done above water, consists of eight cast-iron corner-pieces with boards inserted between them. These corner-pieces are securely bolted together, and form, with the intermediate planking, a framework sufficiently strong for secure construction, on condition that the framing is raised from time to time, as the work proceeds, and that the portion above the deposited concrete is left as low as possible. All the corner-pieces are identical in shape; they are 0·44 metre (1·44 feet) high, and weigh from 60 to 70 kilogrammes (132 to 154 lbs.). The framing for beacon-towers can thus be made to any required size with the same plant, by merely varying the length and spacing of the eight corner-pieces, and employing intermediate planking of suitable length.

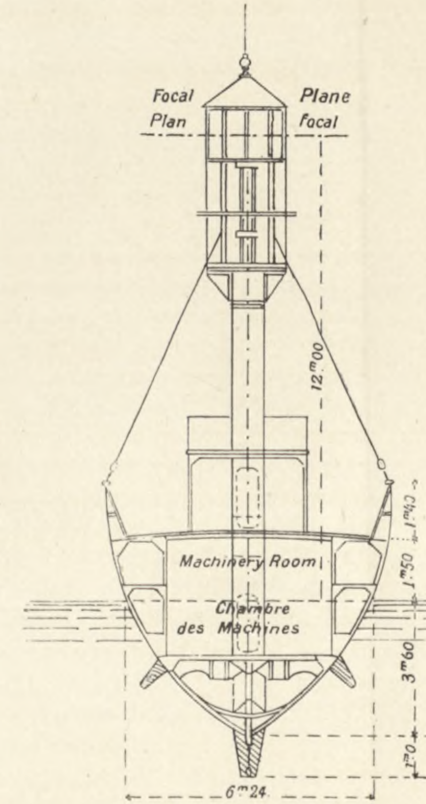
The cement is deposited under water by means of a sail-cloth skip, opening at the bottom. The skip has orifices which allow the water to enter through the lower part as the cement is deposited. This arrangement enables the wetted cement to pass out of the skip when it is opened, without being soaked or washed away by the sea water. Selected blocks of granite, fragments of cast-iron, and pieces of pig-iron are solidly imbedded in the centre of the work, to counterbalance the comparative lightness of the neat cement; this increases the total weight of the tower, without affecting its homogeneity outside the central portion. Mortar made with sand should be used in preference to neat cement for those portions of the work which are left out of water sufficiently long by the fall of the tide. Rubble stone and shingle can be added for the part of masonry above high tide.

The mass of beacon-towers is increased by making them larger, and by increasing their specific weight. During recent years, the increase in volume has been obtained by making the towers higher, in preference to increasing their diameter. These beacons are fairly often raised about 10 metres (33 feet) above high water, thereby increasing considerably their resistance to the action of the waves and their visibility; and they can, if desirable, be provided with a permanent light. The little towers of La Grande Vinotière and Les Vieux-Moines (Finistère) have been built in this manner.

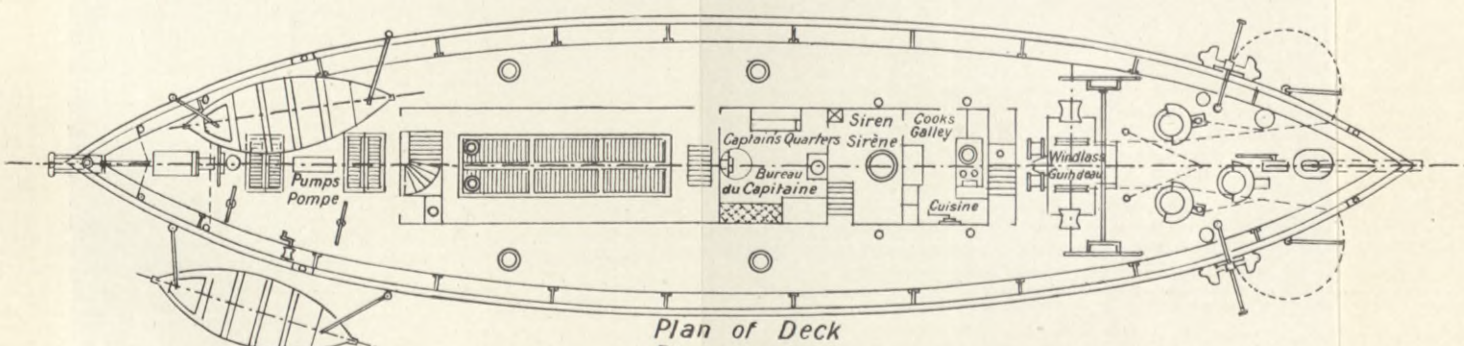
THE "SANDETTIE" LIGHTSHIP.
FEU FLOTTANT "SANDETTIE".



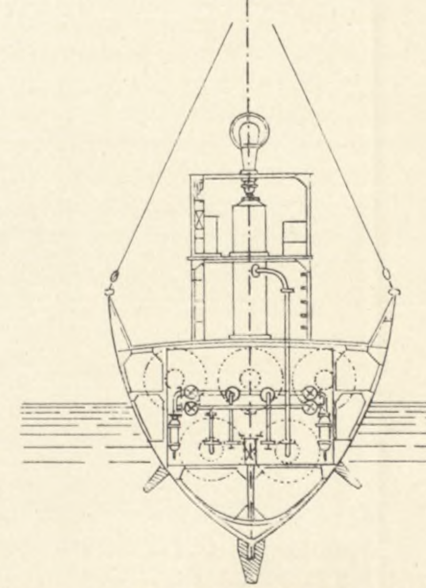
Longitudinal Section
Coupe longitudinale
(Fig. 1)



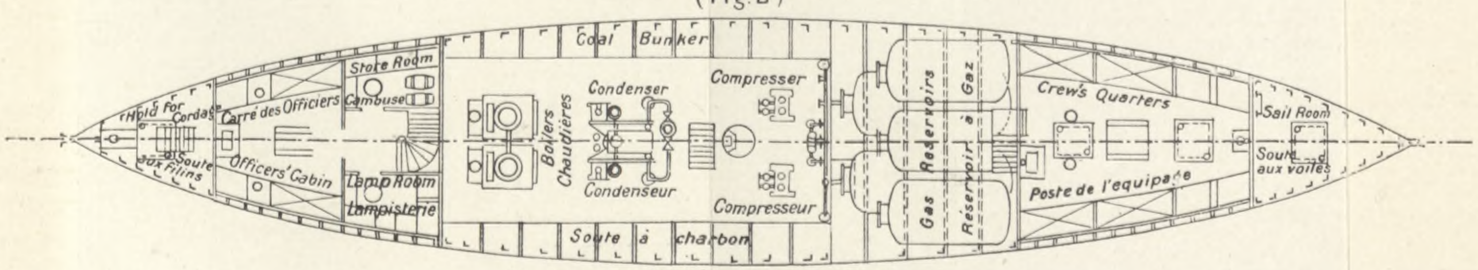
Midship Section
Coupe au maître
(Fig. 4)



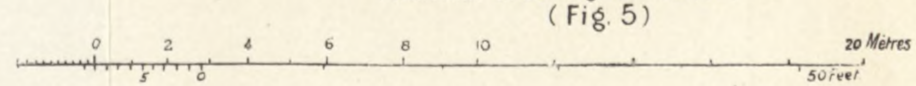
Plan of Deck
Plan du Pont.
(Fig. 2)



Section across Siren and Machinery Room
Coupe transversale dans les compartiments des machines et du signal sonore.
(Fig. 5)



Horizontal Section at the Waterline.
Coupe horizontale à la flottaison.
(Fig. 3)



[Paper.]

THE CHINESE LIGHTHOUSE SERVICE.

By J. Reginald Harding, M.Inst.C.E., Engineer-in-Chief to the Chinese Imperial Maritime Customs Service.

Introduction.

As China has been somewhat conspicuously before the world since the siege of the Legations in Peking last year, and as the question as to what is to become of her, partition or reconstruction, is still unanswered, it is believed that a brief description of the present condition of the lighting of her long coast-line may prove of interest. The Lighthouse Service of China is a department of the Chinese Imperial Maritime Customs, which, under the able guidance of Sir Robert Hart, has practically become the International Civil Service of the country, and embraces within its comprehensive grasp many important undertakings other than the collection of import and export duties.

It is proposed to divide this Paper into seven sections under the following sub-headings: (1) Commencement of the Work of Lighting the Coast. (2) Brief Description of the more important Lights, in chronological order. (3) The Lighting of the Yangtze. (4) Special Points, such as Fog-signalling, Water-supply, Oil Storage, etc. (5) Staff. (6) Buoys and Beacons. (7) System of Construction, Maintenance, and Inspection.

(1) Commencement of the Work of Lighting the Coast.

When the present Inspector-General, Sir Robert Hart, first joined the Customs Service in 1859, the coast of China was practically unlighted, with the exception of a lightship at the mouth of the Yangtze, showing a fixed *white* light; and a few native lights, which were of the most primitive construction, the illuminating apparatus consisting usually of an iron circular dish containing vegetable oil with cotton wicks floating round its edge. Their range seldom exceeded one and a half to two miles; distinctive characteristics were absent; and their exhibition was intermittent and uncertain. A few such lights still exist in out-of-the-way parts of the coast, and possibly prove of some service to fishermen and junk-masters, but they are quite unreliable, and are not included in the official lists of lighthouses.

The work of lighting the coast was commenced in earnest in 1869; and in that year Mr. D. Marr Henderson, M.Inst.C.E., was appointed Engineer to the Lighthouse Department, in which service he remained as Engineer-in-Chief until 1898, when he retired, and was succeeded by the Author, who joined the Chinese Lighthouse Service twenty-one years ago as Assistant Engineer. The designs of far the greater number of the lights in China were prepared by Mr. Henderson, and their construction was carried out under his supervision ; and he may justly look back on his thirty years' work in the East with pride and satisfaction.

(2) Brief Description of the More Important Lights, in Chronological Order.

Prior to 1869 but few lights of any importance had been established.

In 1855, a lightship was placed at the mouth of the Yangtze, off the Tungsha banks. It exhibited a fixed *white* light, which, in 1868, was altered to *red* revolving. In 1870, the light was changed to *white* revolving. In 1871, this vessel was replaced by a wooden lightship, which sailed out from England, and exhibited a catoptric revolving light.* A Holme's steam reed fog-horn was provided, and was sounded every ten seconds during fogs. In 1898–99, a new and greatly improved light-vessel was built in Shanghai from designs prepared in the Engineer-in-Chief's office. The vessel is composite built, with steel frames and teak planking, and her principal dimensions are : length between perpendiculars, 110 feet ; breadth moulded, 25 feet ; depth, 13 feet. The light is catoptric group-flashing, showing three flashes in quick succession every forty seconds. The apparatus consists of three sets of three 21-inch, parabolic, silvered reflectors, with 2-wick mineral-oil burners burning heavy mineral oil (mineral colza), having a flashing point of not less than 250° F. The lantern is cylindrical, 8 feet in diameter, and admits of a keeper entering it to attend to the lights. A first-class double-note fog-siren is provided, driven by air, compressed by two 9½ horse-power Hornsby-Ackroyd oil engines, either engine being capable of sounding the siren singly. The lantern and light cost £1,189, and the fog-signal £1,952. The ship cost about £6,689, exclusive of moorings.

In 1859, three lighted beacons were established in the Canton river.

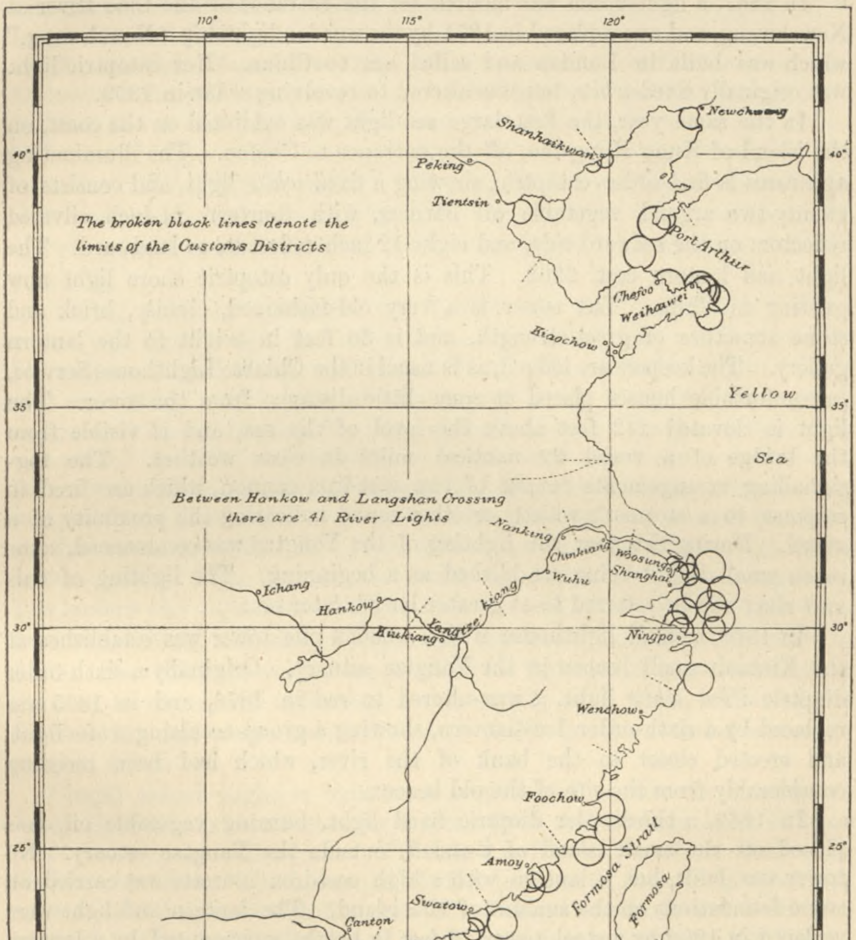
In 1863, a lightship was placed on the Langshan Crossing in the lower Yangtze, and after many alterations, was finally replaced by a buoy in 1877. It is probable that one or more lighted buoys, on Pintsch's system, will shortly be laid down in this part of the river. In the same year a small catoptric light was established on the island of Taetan, near Amoy, and, after being temporarily suspended in 1867, owing to an attack by pirates, who carried off the lighting apparatus, was superseded in 1888 by a dioptric group-occulting sixth-order lens-lantern, shown from an iron trimming hut.

In 1865, a light was exhibited at Woosung, the entrance to the Shanghai river. A new light-tower and keepers' dwellings were built at this spot in 1872 ; and both light and station were improved in 1873, 1875, 1878, and

* The lightships described in this Paper were constructed by Messrs. Dudgeon and Co., of London, the Shanghai Engineering and Shipbuilding Co., Messrs. Boyd and Co., of Shanghai, and by Messrs. Farnham and Co., of Shanghai; the lighting apparatus for lighthouses and lightships by Messrs. Wilkins and Co., Messrs. Chance Brothers, MM. Barbier et Cie., of Paris, and MM. Sautter, Lemonier et Cie., of Paris ; the towers by Messrs. MacLellan, of Glasgow, MM. Barbier et Cie., of Paris, Messrs. Sir William Armstrong and Co., Messrs. Chance Brothers, and MM. Sautter, Lemonier et Cie., of Paris ; the fog-siren machinery by Messrs. Johnson and Co., of Stratford, and Messrs. A. and F. Brown, of New York.

1888; and the light now exhibited is a fourth-order dioptric fixed light, with *white*, *red*, and *green* sectors, indicating the best channel over the outer bar. In the same year, the entrance to Ningpo was lighted by lights on

LIGHTS ALONG THE CHINESE COAST.



Square and Tiger Islands. These lights were replaced in 1872 by a fifth-order fixed *white* light on Square Island, and a sixth-order fixed *red* light on Tiger Island. The lights and lanterns cost £348 and £360 respectively. The towers are both of brick, as are also the keepers' dwellings. The fog-signals consist of a 5-cwt. bell sounded by machinery every fifteen seconds at Square Island, and a gong at Tiger Island. These lights remain as at first exhibited, and suffice for the present limited steamer traffic of the port.

In 1867, a light-vessel was moored off the entrance of the Liao River at Newchwang, and was replaced in 1871 by the wooden lightship "Newchwang," which was built in London and sailed out to China. Her catoptric light was originally fixed *white*, but was altered to revolving *white* in 1899.

In the same year, the first large sea-light was exhibited on the coast, on the island of Kung Kung-tao, off the entrance to Chefoo. The illuminating apparatus is first-order catoptric, showing a fixed *white* light, and consists of twenty-two argand vegetable oil burners, with fourteen 21-inch silvered reflectors on the seaward side, and eight 12-inch reflectors to landward. The light and lantern cost £968. This is the only catoptric shore light now existing in China. The tower is a very old-fashioned, clumsy, brick and stone structure of great strength, and is 30 feet in height to the lantern gallery. The keepers are lodged, as is usual in the Chinese Lighthouse Service, in comfortable houses placed at some little distance from the tower. The light is elevated 242 feet above the level of the sea, and is visible from the bridge of a vessel 22 nautical miles in clear weather. The fog-signalling arrangements consist of two cast-iron cannon, which are fired in response to a steamer's whistle or other sound indicating the proximity of a vessel. During this year the lighting of the Yangtze was commenced, some seven small lights being established as a beginning. The lighting of this vast river will be referred to at greater length later on.

In 1868, a small lighthouse with a wooden pile tower was established at the Kiutoan small beacon in the Yangtze estuary. Originally a sixth-order dioptric fixed *white* light, it was altered to *red* in 1878, and in 1895 was replaced by a sixth-order lens-lantern, showing a group-occulting *white* light, and erected closer to the bank of the river, which had been receding considerably from the site of the old beacon.

In 1869, a third-order dioptric fixed light, burning vegetable oil, was placed on the small island of Gutzlaff, outside the Yangtze estuary. No tower was built, but a lantern with a high cast-iron murette was carried on stone foundations on the summit of the island. The lantern and light were replaced in 1900 by a steel tower 25 feet in height, surmounted by a lantern having an internal diameter of 8 feet 2½ inches with vertical standards and curved glazing. The new light is four-sided third-order dioptric lightning-flashing, and is revolved on mercury. It shows one *white* flash every five seconds, and is the most rapid flashing light on the Chinese coast; and in spite of its great brilliancy, it must be confessed that the exceedingly short duration of the flash causes the system to be less popular with mariners than the older lights with longer flashes, on account of the difficulty of taking accurate bearings. The new tower, lantern, and light cost £2,584.

The light is elevated 283 feet above sea-level, and is visible in clear weather for about 24 miles. Two cast-iron cannon are provided, which are fired during foggy weather in response to any sound indicating the proximity of a vessel. Comfortable brick dwellings are provided for the keepers, and also for the *employés* of the Great Northern Telegraph Co., who, by special permission of the Chinese Government, have a cable-testing station here, and telegraph the arrival of mail steamers, etc.

During 1870, eleven new lights were established on the Yangtze; and a first-order dioptric revolving light showing a *white* flash every minute was exhibited on North Saddle Island, outside the entrance to the Yangtze. The tower, which is 25 feet in height to the lantern gallery, is built of brick, as are also the light-keepers' dwellings. The lantern has vertical framing with horizontal astragals and flat glazing. The light and lantern cost £3,148. In 1899, the 4-wick vegetable oil burner was replaced by a 6-wick mineral oil burner, a larger pressure lamp holding 12 gallons being provided at the same time. The light is elevated 273 feet above sea-level, and is visible in clear weather over 23 nautical miles. The fog-signalling arrangements consist of two cast-iron cannon, fired in response to any sound indicating a vessel's proximity.

During 1871, the lighting of the Yangtze was continued by the addition of six new lights; and first-order lights were established on the coast at Shaweishan, Chapel Island, and Middle Dog. The Shaweishan light is built on a small island to the north of the entrance to the Yangtze. The optical apparatus is first-order dioptric, and originally showed a fixed *white* light, but was altered in 1899 to occulting, at which date the 4-wick vegetable oil burner was replaced by a 6-wick mineral oil burner, and a larger pressure lamp was provided. The lantern is glazed with flat glass, and has inclined standards and horizontal astragals. The tower is of cast-iron, and is 25 feet high to the lantern gallery. The keepers are housed in substantial brick bungalows. The lantern and light cost £2,799; and the cost of altering the light from fixed to occulting, and also of improving the burner and lamp, amounted to £477. Two cast-iron cannon are provided for fog-signalling, and are fired in response to any sound indicating the proximity of a vessel. The light is elevated 229 feet above sea-level, and is visible in clear weather about 22 nautical miles.

Chapel Island Light is built on a small island outside the entrance to Amoy Harbour, and is a first-order dioptric fixed and flashing light showing *white* flashes every half-minute. The upper and lower prisms are fixed, while the lenses revolve. The lantern is 12 feet in diameter, has a high cast-iron murette, and is glazed with flat glass with inclined standards and horizontal astragals. The tower, which is of brick, is 35 feet in height to the lantern gallery. In 1899, a 6-wick mineral oil burner was substituted for the 4-wick vegetable oil one originally supplied. The keepers' dwellings are of brick. The fog-signalling arrangements consist of two cast-iron cannon. A gun-cotton detonating apparatus was tried at this station, but was given up in favour of the guns, owing to the difficulty experienced with the detonators in the climate of China, and to the marked preference of mariners running on the coast for the gun signals. The light is elevated 227 feet above sea-level, and is visible 22 miles in clear weather. Middle Dog is the outermost of a group of islands lying off the mouth of the Min River, the approach to the Treaty Port of Foochow. The lantern and light are similar in all respects to those at Chapel Island, and cost £3,196. The burner was improved from 4-wick vegetable to 6-wick mineral in 1899. The tower is of granite, 35 feet in height to the lantern gallery; and the keepers' dwellings are of brick and granite. Cast-iron cannon are used for fog-signalling with. The light is elevated 257 feet above sea-level, and is visible 23 miles in clear weather.

In 1872, four more lights were established on the Yangtze; and a fourth-order dioptric fixed *white* light was exhibited on West Volcano, on the route between Shanghai and Ningpo. The lantern and light cost £450. The tower is of stone, 20 feet in height to the gallery, and the light-keepers' dwellings are of brick. Fog-signalling cannon are provided. The light is elevated 93 feet above sea-level, and is visible in clear weather 15 miles. During this year range-marks were exhibited at the Woosung Inner Bar, consisting of sixth-order lens-lanterns hoisted on masts, the lower light *white* and the upper one *red*.

In 1873, three more lights were added on the Yangtze; and a first-order light was established on Turnabout in the Formosa Channel, a difficult site to deal with both for construction and for maintenance, on account of its exposed position. The light, which is dioptric first-order, was originally a fixed one with a 4-wick vegetable oil burner; but in 1899 it was altered to occulting, and a 6-wick mineral oil burner was provided. The lantern is 12 feet in diameter, has inclined standards with horizontal astragals and flat glazing; and the lantern and light cost £2,801. The tower is of stone, 25 feet high to the gallery, and the keepers' dwellings are of brick. Cast-iron cannon are provided for fog-signalling purposes. The light is elevated 257 feet above sea-level, and is visible 23 miles in clear weather. This station has suffered more damage from typhoons than any of the other Chinese lighthouses.

In 1874, the largest island of the Lamocks group, outside the entrance to the treaty port of Swatow, was lighted by a first-order light on its summit, and a fourth-order low light sending a *red* beam to the southward over certain dangers known as Boat and White Rocks. The first-order light is dioptric, and originally showed a fixed *white* light, which was changed to *white* occulting in 1899, the 4-wick vegetable oil burner being at the same time replaced by a 6-wick mineral oil one. The lantern and light are similar to those on Shaweishan and Turnabout. The tower, which is 25 feet high and of cast-iron, cost £1,305. The keepers' dwellings are of brick. Cast-iron cannon are used for fog-signalling purposes. The light is elevated 241 feet above sea-level, and is visible 22 miles in clear weather. The low light is exhibited from a brick building on the southern slope of the island. It is a fourth-order dioptric condensing light, showing a *red* arc of 16 degrees over the Boat and White Rocks. The apparatus cost £220.

In this year, 1874, the north-east promontory of Shantung was marked by a first-order dioptric light, which originally showed a fixed *white* light with *red* sectors over Alceste Island and Martha Point, but was changed to occulting in 1892, when a 6-wick mineral oil burner with a fountain lamp was provided. The lantern is 12 feet in diameter, with a high cast-iron murette, and has flat glazing with inclined standards and horizontal astragals. The lantern and light, including the dioptric mirror, burners, etc., cost £3,131. In 1876, the burners and lamps were changed at a cost of £148. The extra cost of the occulting machinery and new burners provided in 1892, was £373. The tower is of stone, 35 feet in height to the gallery; and the light-keepers' dwellings are of brick. The centre of the light is 220 feet above sea-level; and the light is visible about 22 miles in clear weather.

In 1893, a powerful first-class double-note fog-siren was erected at this station. The siren is sounded by compressed air, which is supplied from two store-holders, filled to a pressure of 100 lbs. per square inch by two 11 H.P. Priestman oil engines. The machinery cost £3,002; and the siren house, which is a substantial brick building with an iron and concrete roof, and water and oil tanks in the basement, cost $4,010, or about £401. The signal, which is sounded during foggy weather or snow-storms, consists of two blasts, high and low, every two minutes.

In 1875, a first-order eight-sided dioptric revolving light, showing a *white* flash every minute, was exhibited on Ocksen Island in the Formosa Channel. The lantern is 12 feet in diameter, and has a high cast-iron murette, rectangular framing, and curved glazing. A 6-wick Doty burner is used with a fountain lamp. The lantern and light cost £3,321. The tower is of stone, 35 feet in height to the lantern gallery; and the keepers' dwellings are of brick. Cast-iron cannon are provided for fog-signalling purposes. The light is elevated 286 feet above sea-level, and is visible 24 miles in clear weather.

In the same year, fourth-order fixed lights were established on Fisher Island in the Pescadores, and on Tsingseu Island, at the entrance to Amoy Harbour. The latter light has *red* cuts over the Chauchat Rocks and inshore of Fort Point. The tower on the Pescadores is of cast-iron, 20 feet in height to the gallery; and the lantern, light, and tower cost £901. The keepers' houses are of brick and stone. The light was built on the site of an interesting old Chinese light-tower, which was not, however, considered sufficiently trustworthy to carry the new lantern. The Fisher Island Light is now in the hands of the Japanese Government. The tower at Tsingseu is octagonal and built of brick, and is 20 feet high to the gallery. The lantern and light cost £501. Fog-signalling cannon are provided at both these stations.

In 1877, one new river-light was exhibited in the Yangtze.

In 1878, two new light-vessels were established, one on the Kiutoan flats in the Yangtze estuary, and the other off the Taku Bar at the entrance to the Peiho. The former vessel is a composite ship, 81½ feet long by 21½ feet beam and 10¼ feet deep, with iron framing and teak planking. The light was originally catoptric, showing a fixed *white* light from sixteen 12-inch silvered reflectors. It was altered to revolving in 1899, by grouping nine of the original reflectors into three faces; and it now shows a *white* flash every half-minute. During foggy weather a 10 cwt. bell is struck three double blows every minute by machinery. The lantern and light cost £766; and the fog-bell cost £245. The first light on the Taku Bar consisted of three sixth-order lens-lanterns, showing a fixed *white* light exhibited from the hulk "Aden." This hulk capsized at her moorings in 1879, and in 1880 a sister-vessel to the "Kiutoan" was placed on the station, and has since 1887 shown a catoptric revolving light giving *white* flashes every half-minute. During foggy weather, which is of rare occurrence at Taku, a gong is sounded at one-minute intervals. In both ships the lights are elevated 35 feet above the sea, and are visible 11 miles in clear weather.

In 1880, the entrance to the treaty port of Swatow was lighted by the exhibition of a fourth-order dioptric light on Good Hope Cape, and a sixth-order dioptric light on Sugarloaf. The light on Good Hope Cape is carried on a cast-iron tower 9 feet 10½ inches high to the lantern gallery. The lantern is 6 feet 7 inches diameter inside the glazing, which is curved; and the standards are vertical. The optical apparatus is arranged to show a fixed *red* light from S. 32° E. to S. 10° E., an occulting *white* light from S. 10° E. round by S. and W. to N. 8½° E., and an occulting *red* light from N. 8½° E. until cut off by Ma-urh Point. The occultation is performed by a blackened vertical screen revolving round the apparatus; and the *red* sector for Ma-urh Point is produced by simple ruby shades arranged inside the lantern. The *fixed red* light is produced by the use of a holophote on the landward, or blank arc side, which throws its light on to a panel of five vertical condensing prisms which divert the rays through ruby shades in the lantern, and by direct rays from the apparatus passing through other ruby shades. Thus, when the direct light from the optical apparatus is eclipsed by the screen, the light from the condensing prisms remains visible, and *vice versâ.* The keepers' dwellings are of brick. Cast-iron cannon are provided for fog-signalling purposes.

Sugarloaf Light is exhibited from a small cast-iron tower, 9 feet 6 inches in height, and consists of a sixth-order dioptric apparatus showing a fixed *white* light varied by *red* flashes at half-minute intervals. These *red* flashes are produced by vertical red refractors which are revolved round the apparatus. The lantern has curved glazing and vertical standards. The light-keepers' dwellings are of brick. In this year a first-order light was placed on one of the most important and dangerous turning-points on the coast, Breaker Point, about 30 miles south of Swatow. As the site is a low one, a tower of considerable height was required, and it is 92 feet to the lantern gallery, with a total height of 120 feet to the vane. It consists of a wrought-iron cylinder or tube, containing the staircase, enlarged at the top to a diameter of 12 feet, to form a service room and to carry the lantern; and it is stayed with eight large wrought-iron stays, arranged in pairs, braced together and secured to anchor bolts embedded in Portland cement concrete. The tower was designed by Mr. George Rendel, and cost £4,556. The lantern has a low murette with curved glazing, inclined standards, and horizontal astragals. The light is first-order dioptric *white* occulting, the occultations being produced by a light iron cylinder, of slightly larger diameter than the burner, alternately raised and lowered by suitable clockwork mechanism. *Red* cuts are arranged over outlying dangers up and down the coast; and vertical condensing prisms are employed for strengthening the cuts. A 6-wick mineral oil burner is used with a fountain lamp. The lantern and light cost £3,077. The keepers' dwellings, which are extensive, are of brick. Fog-signalling is carried out with cast-iron cannon. The light is elevated 152½ feet above sea-level, and is visible 19 miles in clear weather.

In 1882, first-order lights were established on Howki Island and on Dodd Island. Howki Island is in the Gulf of Pechili, in the direct track of steamers running between Chefoo and Taku; and the light is first-order dioptric 8-sided revolving, showing a *white* flash every half-minute. The lantern has inclined standards, horizontal astragals, and curved glazing; and the cast-iron murette is 4 feet 6 inches high. The tower, which is of dressed granite, is 20 feet high to the lantern gallery. The keepers' houses are also of dressed granite. Cast-iron cannon are provided for fog-signalling. The light is elevated 328½ feet above sea-level, and is visible 25 miles in clear weather.

Dodd Island is a small island situated close to the coast about 25 miles north-east of Amoy, and has a dangerous outlying reef known as Dodd Ledge. The light is first-order dioptric *white* occulting, with *red* sectors over the dangers to the north and south. The lantern is 13 feet in diameter with a 4 feet 6 inches cast-iron murette, and has curved glazing with inclined standards and horizontal astragals. The occulting machinery is similar to that at Breaker Point. The lantern and light cost £3,198. The tower, which is 50 feet high to the gallery, is a handsome brick structure with granite lintels, sills, gallery, and stringer courses, and is constructed with double walls having an annular ventilating space between them. This tower was built at the low cost of 8,106 Mexican dollars, or about £810 at the present rate of exchange. The keepers' dwellings are of brick. Cast-iron cannon are used for fog-signalling. The centre of the light is elevated 147 feet above sea-level; and the light is visible 18 miles in clear weather. In this year, a small dioptric fixed light was placed on Fort Zealandia at Anping, Formosa, as a guide to vessels coming to an anchorage in the roadstead.

In 1883, the south cape of Formosa was lighted by a first-order dioptric fixed *white* light, with a *red* sector over the south-west cape. This lighthouse was of somewhat exceptional construction, and had to be fortified, as the district in which it was built is inhabited by savages. The lantern, which had curved glazing and rectangular framing, had revolving steel shutters to protect the glass in case of an attack. The lantern gallery was loopholed for rifle fire, and carried a five-barrelled Gatling gun on gun-metal racers. The tower was of cast-iron, 50 feet high to the gallery, 19 feet 6 inches diameter at the base, and 12 feet 8 inches at the top. It was fitted up with living rooms for the foreign staff to use in case of attack. Round its base was a wrought-iron fort, 40 feet in diameter, containing living rooms for the native staff, store-rooms, a kitchen, and an armoury; and water cisterns were arranged in the basement. The staff usually lived in large brick bungalows, each room in the bungalows being connected with the wrought-iron fort by a bullet-proof passage. The compound was protected by a loop-holed brick wall, and a 20-foot ditch flanked by *caponnières;* and a barbed wire fence crowned the summit of the glacis. In addition to the ordinary staff, a guard of eight men was employed under a European gunner; and the station was armed with two Gatling guns, one Cohorn mortar, and two 18-pounder cannon. As the landing on the coast at South Cape was difficult, and was frequently exposed to a heavy swell, a small creek in the coral was cleared of rocks with dynamite, and a concrete jetty 170 feet long was built on the side of the creek. The tower and refuge cost £5,881; and the light and lantern cost £3,223. The local expenditure for buildings, etc., amounted to 71,248 Mexican dollars, or about £7,125 at the present rate of exchange, or £13,656 at the rate of exchange when the station was built.

The local expenditure was divided as follows:—Labour, $24,903; materials, $19,983; gear and plant, $2,877; transport, $20,313; temporary houses, $1,232; incidental, $1,940; total, $71,248.

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The light was elevated 180 feet above sea-level, and was visible 20 miles in clear weather. The station was, unfortunately, partially destroyed during the Chinese-Japanese war. Formosa and the Pescadores are now in possession of the Japanese, who have made some progress in lighting these islands.

In this year, 1883, third-order dioptric revolving lights were erected on Steep and Bonham Islands in the Chusan Archipelago, on the main trade route to Shanghai. These lights are similar in all respects, excepting the optical apparatus, which in the case of Steep Island shows *white* flashes every half-minute; while at Bonham the flashes are alternately *white* and *red* of equal intensity, the lenses for the *red* flashes subtending an angle of 65° in azimuth, and those for the *white* 25°. The towers are of cast-iron 25 feet high from base to gallery. The lanterns have curved glazing with rectangular framing, and high cast-iron murettes. The towers cost £700 each; and the lanterns and lights for Steep Island cost £1,234, and £1,316 for Bonham. The keepers' dwellings are of dressed stone. Cast-iron cannon are used for fog-signalling. Both lights are visible 22 miles in clear weather, being elevated 243 and 237 feet above sea-level respectively.

Another important lighthouse was completed in this year at the south-east promontory, Shantung. The light is first-order dioptric eight-sided revolving, showing one *white* flash every half-minute. The lantern is 12 feet in diameter, has curved glazing with rectangular framing, and a cast-iron murette 7 feet 6 inches high. The tower, which cost £2,828, is a very handsome and highly finished cast-iron structure, 50 feet in height to the gallery. The light and lantern cost £3,412. The keepers' dwellings are of dressed stone. It was near this spot that the German man-of-war "Iltis" was lost with nearly all hands in 1896. As fogs are very prevalent on the Shantung promontory, a first-class single-note steam fog-siren is provided, and gives a blast of four seconds' duration at intervals of one and a half minutes. The siren machinery, with duplicate boilers, cost £1,691. The light is elevated 96½ feet above sea-level, and is visible in clear weather over 15½ miles. In the same year, a small sixth-order dioptric fixed *white* light was exhibited at Saracen's Head, at the port of Takow, in Formosa.

In 1886, a couple of small lights were added to the list of Yangtze lights; and a sixth-order dioptric fixed *white* light, in a dwarf lantern, was placed on a brick tower, 43 feet in height, which had been built by the Chinese on the sandbank of Tsao-fei-tien near Taku. The light has been changed this year to fourth-order dioptric group-flashing, showing double *white* flashes every twenty seconds. The apparatus is floated on mercury; and the lantern has curved glazing with vertical standards, and a low wrought-iron murette. The lantern and light cost £954. As the sandbank has recently shown signs of erosion, the base of the tower has been protected by a short wall, and a brick dwelling-house has been built for the light-keepers, raised 6 feet above ground level. The light is visible 12½ miles in clear weather.

In 1888, the Tamsiu Bar in northern Formosa was lighted by two range-lights of the sixth order. Both are dioptric; and the upper one is carried on an iron column, and shows fixed *white*; while the lower one is placed on a wrought-iron screw-pile tower, the base of which is awash at half-tide, and shows fixed *white* over the navigable channel, with *red* and *green* sectors on either side.

In 1890, a fourth-order dioptric fixed *white* light, with *red* sectors over certain dangers, was exhibited on Loka Island, in the Chusan Archipelago. The tower is of stone, 17 feet high to the gallery; and the light, which is elevated 128 feet above sea-level, is visible 15 miles in clear weather. The light-keepers' dwellings are of brick. In the same year, a new sixth-order lens-lantern showing a fixed *white* light, and hoisted on an iron lattice-work mast, was erected at Anping in place of and further to seaward than the Fort Zealandia light.

In 1891, the harbour light at Port Arthur was taken over by the Lighthouse Department, and, after being partially destroyed in the Chinese-Japanese war in 1894, was re-established as a sixth-order dioptric group-occulting light, showing *red* sectors to the westward and over Lutin Rock. The light, now in the hands of the Russians, was a lens-lantern exhibited from an iron trimming hut; and the ruby shades giving the red cuts were arranged in frames on the roof of the hut. In the same year, the Wei-hai-wei lights were handed over to the Lighthouse Service by Admiral Ting. They consisted of a sixth-order lens-lantern on a mast on Observatory Island, and a fourth-order dioptric revolving light on a cast-iron tower on Chao-pei-tsui Point. The former was destroyed during the Chinese-Japanese war, and was not replaced; but when Wei-hai-wei was re-lighted, under the Author's supervision, in 1898, a new light was placed on Flagstaff Point in the harbour. This light is now fourth-order dioptric group-occulting, showing arcs of *white* light over the safe channels in the two entrances to the harbour, and *red* elsewhere. It is carried on a short wrought-iron tower; its cost amounted to £1,061. The keepers are lodged in a rubble stone hut. The Chao-pei-tsui cast-iron tower is 21 feet in height to the gallery; the revolving light shows one *white* flash every half-minute. The keepers' dwelling-house is of rubble stonework. These Wei-hai-wei lights are now under the administration of the British Government, but are still managed by the Chinese Lighthouse Service. In this year of 1891, sixteen new small lights were exhibited on the Canton river, and one on the Yangtze.

In 1892, three more small lights were established on the Yangtze.

In 1893, first-order dioptric group-flashing lights were exhibited on Waglan Island, and at Lao-tieh-shan. Waglan is a small island just outside the entrance to Hong Kong; and the light, which is the first first-order light ever floated on mercury, is a four-sided one, each side containing a group of two lenses, and double *white* flashes are shown every half-minute. The lantern has curved glazing and rectangular framing, and a high cast-iron murette, with a porch on the gallery. The tower is of cast-iron, 25 feet high to the gallery. The tower, lantern, and light cost £5,092; and the local expenditure for dwellings, etc., amounted to about £3,711. The keepers' dwellings are of stone and brick. The island is a difficult one to land on, and during the north-east monsoon reliefs and stores have frequently to be landed with the derrick crane at the landing place. Fog-signalling is carried out with 18-pounder cannon. The light is elevated 225 feet above sea-level, and is visible 22 miles in clear weather. This lighthouse was taken over by the British Government in March of this year.

Lao-tieh-shan is the southern extremity of the Liao-tung peninsula, about nine miles distant from Port Arthur. The lantern, light, and tower are in every respect duplicates of those at Waglan, and cost practically the same. The buildings are of stone and brick; cast-iron cannon are provided for fog-signalling purposes. The light is elevated 315½ feet above the sea-level, and is visible 25 miles in clear weather. This lighthouse was taken possession of by the Russians in 1898.

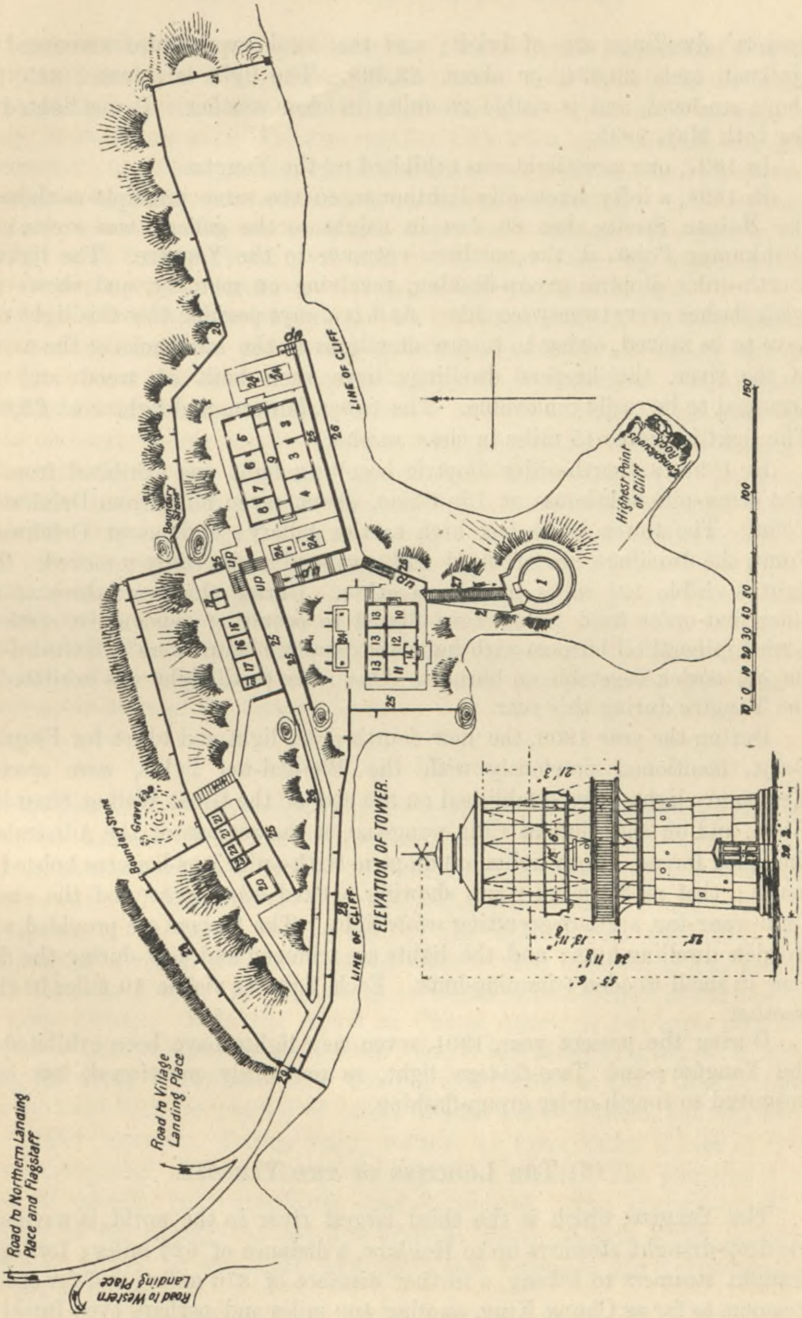
In 1893, the Feima Channel across the Woosung Bar was marked with range-lights, the old bar-marks being afterwards abolished. One new light was established on the Yangtze in this year.

In 1894, the lighting of the Hainan Straits was commenced; and in this year, a sixth-order revolving dioptric light, floating on mercury, showing three *white* flashes followed by a *red* one, was exhibited in Hoihow Harbour. The light is carried on a small wrought-iron tower; the tower, lantern, and light cost £827. The dwellings, which are of considerable extent, in order to act partly as a sanatorium for the Customs staff at Hoihow, are of stone.

In the same year, Lamko Point on Hainan Island, at the western entrance of the strait, was lighted by a fourth-order dioptric bivalve light revolving on mercury, and showing one *white* flash every twenty seconds. The lantern has curved glazing and vertical standards, with a low wrought-iron murette. The tower, which is 55 feet high to the gallery, consists of a wrought-iron cylinder carrying a spiral staircase, and supported by six inclined wrought-iron piles, securely braced and strutted. The foundation consists of twelve screw piles, six for the ends of the inclined piles, and six for the central cylinder. The point on which the tower is erected is only a few feet above high-water, but it is well protected from the sea by outlying reefs. The dwelling-houses are built of dressed stone. The tower, lantern, and light cost £2,583; the light is visible 13½ miles in clear weather.

Early in 1895, a fourth-order dioptric light, revolving on mercury, showing a double *white* flash every half-minute, was exhibited on the mainland on Cape Cami, immediately opposite to Lamko. The site is only a few feet above high-water; and the tower is of similar construction to that at Lamko. The tower, lantern, and light cost £2,462.

In this year, a very fine hyper-radial light was exhibited on Pei Yü-shan Island, about 200 miles to the south of Shanghai (*see plan*). The apparatus, which is 2·66 mètres (8 feet 8 inches) in diameter, and 3·645 mètres (12 feet) high, is an especially beautiful piece of work, and is floated on mercury. The apparatus, with its cast-iron table, pivot-shaft, etc., weighs rather over 15 tons; yet so well does the mercury system minimise friction that it can easily be pushed round with the little finger. The light is group-flashing, showing double *white* flashes every half-minute; and the apparatus has four pairs of panels. The flashes will have a duration of about 1⅗ seconds, and the eclipses will be alternately of about 5 and 21⅗ seconds. The lantern is 15 feet 4 inches in diameter, and the glazing, which is curved, is 12 feet 10 inches high. The cast-iron murette is 7 feet 6 inches in height, and is lined with galvanised iron. The lantern framing is rectangular; and the lantern is braced from its cornice to the gallery balustrade by light diagonal steel stays. The tower is a massive cast-iron structure, 25 feet to the gallery (*see elevation*). The light-tower stands a little to the north-west of the remarkable cliff which forms the south-eastern extremity of Pei Yü-shan, which is marked on the British Admiralty chart No. 1759, as Sha Ho I. The tower, lantern, and light cost £8,972. The



REFERENCE TO FIGURES IN ILLUSTRATION.

1. Lighthouse tower.
2. Lightning-conductor and earth-plate.
3. Chief Keeper's room
4. Second ,, ,,
5. Spare room
6. Lights stores
7. Boys' room
8. Kitchen
9. Passage

(3–9: Foreign dwellings.)

10. Chief Keeper's room
11. Assistant ,, ,,
12. Coolies' room
13. Kitchen
14. Lobby

(10–14: Native dwellings.)

15. Foreign Keeper's store.
16. Native ,, ,,
17. Coal.
18. Bathroom.
19. W.C.'s for foreign keepers.
20. Oil store.
21. Hen houses.
22. Pigstyes.
23. W.C. for native keepers.
24. 6 water-tanks, each 2,060 gals.
25. Retaining walls.
26. Parapets.
27. Slips up to tower.
28. Boundary walls.
29. Entrance gate.

keepers' dwellings are of brick; and the local expenditure amounted to Haikuan taels 20,394, or about £3,398. The light is elevated 345 feet above sea-level, and is visible 26 miles in clear weather. It was lighted on the 28th May, 1895.

In 1897, one more light was exhibited on the Yangtze.

In 1898, a lofty screw-pile lighthouse, on the same principle as those in the Hainan Straits, but 80 feet in height to the gallery, was erected on Drinkwater Point, at the northern entrance to the Yangtze. The light is fourth-order dioptric group-flashing, revolving on mercury, and shows two *white* flashes every twenty seconds. As it is always possible that this light may have to be moved, owing to future alterations in the sandbanks at the mouth of the river, the keepers' dwellings have been built of wood and are arranged to be easily removable. The tower, lantern, and light cost £3,033. The light is visible 15 miles in clear weather.

In 1899, a fourth-order dioptric occulting light was exhibited from an iron screw-pile lighthouse at Liu-Chiao, about seven miles from Drinkwater Point. The tower is 40 feet high to the gallery; and, as at Drinkwater Point, the dwellings are of wood and arranged to be easily removed. The light is visible 12½ miles in clear weather. During this year, three of the older first-order fixed lights were altered to occulting; and at six stations, 6-wick mineral oil burners with improved pressure lamps were substituted for the old 4-wick vegetable oil burners. One more small light was exhibited in the Yangtze during this year.

During the year 1900, the new fourth-order light and tower for Flagstaff Point, mentioned previously with the Wei-hai-wei lights, were erected. Temporary lights were established on the end of the Great Wall at Shan-hai-Kuan, and on the bluff at Chin-wang-tao, at the request of the Admirals of the allied forces. Both lights are dioptric sixth-order lens-lanterns hoisted on masts; that at Shan-hai-Kuan showing a fixed *white* light, and the one at Chin-wang-tao, a group-occulting *white* light. The keepers are provided with wooden dwelling-huts; and the lights are trimmed and kept during the daytime in small wooden trimming-huts. Each light is visible 10 miles in clear weather.

During the present year, 1901, seven new lights have been exhibited on the Yangtze; and Tsao-fei-tien light, as previously mentioned, has been improved to fourth-order group-flashing.

(3) The Lighting of the Yangtze.

The Yangtze, which is the third largest river in the world, is navigable for deep-draught steamers up to Hankow, a distance of 620 miles; for light-draught steamers to Ichang, a further distance of 370 miles; and for special steamers as far as Chung King, another 400 miles and perhaps even further.

It is divided for lighting purposes into four sections:—(1) The Estuary, the lighting of which has been briefly described in the previous section of this Paper; (2) the Lower river between Hankow and Woosung; (3) the Middle river between Hankow and Ichang; (4) the Upper river, all above Ichang.

The steamer traffic on the Lower river, both in numbers and tonnage, is very considerable; and this portion of the river may now be considered to be fairly well lighted. The lighting of the Middle river is only in its initial stage, partly because traffic has hitherto been small, and partly because in many places, owing to the extreme rapidity with which the river-bed changes, steamers are unable to move at night, and have frequently to re-survey certain crossings with their own steam launches before proceeding. It is unlikely that any lighting could ever make the Upper river navigable at night, as the dangers even by day are so great that of the two commercial steamers that have been put on that route, one was lost on her very first voyage.

One of the difficulties of dealing with the Yangtze is the great difference in water-level between winter and summer, amounting at Ichang and at Hankow to nearly 50 feet, and at Chungking to over 90 feet. At low-water all sunken dangers come into prominence; while at extreme high-water the banks and surrounding country are all submerged, and landmarks obliterated. What is chiefly needed is the marking by night and day of certain well-known landmarks and turning points, range-lights on certain crossings, and marks for certain existing dangers. Sixth- and seventh-order lens-lanterns showing fixed *white* or *red* lights, and managed by native keepers, have been found most suitable for this purpose; and the shore lights are exhibited from masts, the keepers being housed in native huts. The floating lights are carried by small light-boats cheaply built on the lines of native craft. There are now thirty-five shore lights, and eighteen light-boats on the Lower and Middle Yangtze, exclusive of the Estuary lights.

(4) Special Points.

Fog-Signalling.—Cast-iron cannon are used for fog-signalling, excepting at four shore stations where there are continuous signals, and on light-vessels. Most of these cannon are 12- or 18-pounders, and fire charges of 3 lbs. of black powder. The signals are not continuous, but are fired in foggy weather in response to fog-horn, whistle, bell, or any other sound indicating the proximity of a vessel, and are repeated after a fixed interval if the sound continues to be heard. The signals are arranged to be different at stations in the same district. Thus the signal at Chapel Island is two guns with an interval of three minutes between them; and if the vessel's fog-signal is still heard, the firing is repeated after ten minutes; while at Dodd Island, two guns are fired with an interval of half a minute between them, and repeated after fifteen minutes. During foggy weather an extra watch is kept in the station compound, to listen for the fog-signals of vessels. The gunpowder is stored in specially built magazines carefully isolated. The average number of hours of fog during the last five years at eleven stations, which occupy prominent points on the coast, and fairly well represent the entire coast-line, was as follows:—

	hours.		hours.		hours.
Lamko	362	Ockseu	408	N.E. Shantung Promontory .	819
Waglan . . .	262	Turnabout . . .	970	Howki	365
Breaker Point .	506	Pei Yü-shan . .	689	Taku	223
Chapel Island . .	458	Gutzlaff	549		

Water-Supply.—Each station is provided with large underground water cisterns lined with Portland cement, and covered either with brick arches or with dressed stone. The storage capacity at a first-order station varies from 10,000 to 18,000 gallons; and water is collected entirely from the roofs of the dwellings, which are usually covered with corrugated galvanised iron. This water-supply has been always found to be pure and sufficient.

Oil Storage.—The mineral oil is not stored in bulk in tanks at the stations, but remains in the original tins supplied by the manufacturers, which are kept in specially ventilated isolated oil-stores.

Landing Huts.—As the landing places are in many cases a long way from the lighthouses, store huts are sometimes erected at or near the landing place, into which all stores are placed by the crew of the tending steamer, and are carried up to the station by the staff later on as time permits.

(5) Staff.

All the more important coast-lights have to be in charge of foreign light-keepers; while the small lights are looked after by native keepers who have received long training at the hands of foreigners. The larger stations have two, sometimes three, foreign keepers; and the usual minimum staff for the first-order lighthouse on the coast is two foreign keepers, two native keepers, and two coolies. The Yangtze lights are each managed by two native keepers. A first-class lightship is manned by a foreign captain and two foreign mates, and a native crew consisting of two engineers, one carpenter, three lamp-trimmers, and six sailors.

There are now in the service about 67 foreign captains, mates, and light-keepers, and 207 native keepers, besides a considerable number of coolies, many of whom are competent to stand a watch alone. The foreign staff is divided into captains, mates, chief keepers A, chief keepers B, second keepers A, second keepers B, third keepers A, and third keepers B; and the rates of pay, per mensem, are as follows: Captains, a maximum of Haikuan taels 200, say, £30 6*s*. 3*d*.; mates, a maximum of Haikuan taels 100, say, £15 3*s*. 1½*d*.; and keepers from a maximum of chief keepers A, Haikuan taels 120, say, £18 3*s*. 8*d*., to a minimum of third keepers B, Haikuan taels 60, say, £9 1*s*. 10*d*. The native keeper's pay varies from 25 Haikuan taels, say, £3 15*s*. 9*d*., to 5 Haikuan taels, say 15*s*. 2*d*., per mensem. Foreign keepers receive a bonus of one year's pay after ten years' service, and are granted one year's leave on half-pay during the same period. They are also allowed one month's leave in the year. Native keepers receive a bonus of one month's pay every year after three years' service, and are allowed a month's leave in every twelve months.

(6) Buoys and Beacons.

There are at present eighty-eight buoys watching on the coast, including four of Courtney's whistling buoys, one bell buoy, and one exhibiting a Wigham's petroleum buoy light. The service buoys are made in two sizes, 10 feet diameter and 6 feet diameter, and are surmounted by bamboo cages of various shapes. They are now usually constructed of steel, and are divided into compartments. The moorings are mushroom anchors, and iron or stone sinkers ; and at the suggestion of the Coast Inspector, cement concrete sinkers are now being economically constructed. Fourteen gas-lighted buoys on Pintsch's system are in course of construction for the Yangtze estuary and it is likely that this system will eventually be further extended. There are seventy-eight beacons of iron, stone, and wood in position.

Both buoys and beacons are coloured on a uniform system. The colour of buoys, with directions and explanations, will be found in the Appendix (p. 189).

Wreck-marking Boats.—The distinguishing sign of a wreck-marking boat at night is either one *red* light or a *red* light with a *white* light vertically below it. By day, such a boat exhibits a *red* flag, or such other *mark* as may be locally notified.

(7) Construction, Maintenance, and Inspection.

The head of the Chinese Lighthouse Service is Sir Robert Hart, Inspector-General of Customs. Sites for new lights are chosen by the Coast Inspector and the Engineer-in-Chief in consultation. The necessary designs and estimates are then prepared by the latter, and submitted to the Inspector-General for his approval and sanction. All local financing is undertaken by the Commissioner of the Port in whose district the lighthouse is to be built ; and the contracts for the lanterns, lights, etc., required from Europe, are usually put up to open competition by the London Secretary of the Customs Service, under instructions from the Inspector-General. The actual work on the site, the erection of the various buildings, etc., are seldom done by contract, but are generally carried out by a Resident Engineer, under the supervision of the Engineer-in-Chief. Labour being cheap in China, labour-saving appliances are few, and not necessary. The lighthouse having been completed, and the light exhibited, it is handed over by the Engineers' Department to the Chief of the district in which it has been built ; and a notice to mariners is issued by the Coast Inspector by order of the Inspector-General. Local notices are issued, if necessary, signed by the harbour master of the nearest port, and approved by the Commissioner.

Maintenance.—The coast is divided into seventeen lights districts.

The lights in each district are officially under the Commissioner of the Port ; but for convenience in working, the Shanghai and Ningpo districts are controlled by the Coast Inspector's office in Shanghai ; and the Swatow, Amoy, and Foochow districts are managed from Amoy, where an Inspector of Southern Lights is established. The headquarters of the Lights Service are in Shanghai, where the Engineer-in-Chief and Coast Inspector have their establishments, and where there is a large depôt containing oil go-downs, stores, buoy-shed, experimental lantern, boat-shed, etc., and where oil-gas works will shortly be erected. The lights on the coast are communicated with at least once a month, in some cases by steamer, in others by sailing tenders, and in a few instances by couriers.

The lighthouse tender " Ping-Ching " is stationed in Shanghai and does most of the heavy work on the coast, taking out yearly supplies, etc., and carrying the Engineer-in-Chief and Coast Inspector on their tours of inspection. This vessel is 230 feet in length by 30 feet in beam, and, having ample hold accommodation, is useful in building work ; but she is unable to cope with all the work required, and is at present assisted by one or more of the Revenue cruisers. These ships, being purely men-of-war, are entirely unfitted for lighthouse work; and the Inspector-General is now building a new twin-screw light-tender, 195 feet long by 28½ feet beam. Sailing tenders are stationed at Newchwang, Chefoo, Ningpo, Amoy, Swatow, and Hoihow; and a small steam buoy-barge is stationed at Foochow. The Yangtze lights are tended at present by sailing craft; but it is proposed to build two steam launches for this work.

Inspection.—Usually each light on the coast is inspected once a year by both the Coast Inspector and the Engineer-in-Chief. Lights are liable to inspection at other times by the Inspector of Southern Lights, and by the harbour-masters of the ports in whose district they are, and by the captains of Customs cruisers.

The light-keepers keep a complete set of books, including Daily Journal, Monthly, Quarterly, and Yearly Sheets of Expenditure of Stores, Meteorological Records, Order Book, Visitors' Book, Letter Book, Property Book, Signal Book, Stores Book, and Defect Book; and at the more important stations meteorological observations are taken every three hours, and the records thus obtained are supplied to the observatories at Shanghai and Hong Kong.

The total number of lights, etc., now under the control of the Service is:—Lights, 98; light-vessels, 4; light-boats, 20; buoys, 88; beacons, 78.

In addition to the above, there are no less than seventeen lights on the coast and in Formosa in the hands of other nations.

APPENDIX.

Buoys. No.	Buoys. Colour.	Directions and Explanations.
1	Red	Entering the channel from seaward, *red* buoys will be found on the *starboard* side of the channel, and must be left on the *starboard* hand by vessels passing in.
2	Black	Entering the channel from seaward, *black* buoys will be found on the *port* side of the channel, and must be left on the *port* hand by vessels passing in.
3	Red and black horizontal bands.	Buoys painted in *red* and *black horizontal bands* will be found in the fairway, and should be passed close-to.
4	Red and black vertical stripes.	Buoys painted in *red* and *black vertical stripes* will be found on the ends of spits, and the outer and inner extremes of banks, shoals, or extensive reefs, where there is a navigable channel on either side of such spit, bank, shoal, or reef. Vessels should never attempt to pass between a buoy thus painted and the danger which it marks.
5	Red and black chequers.	Buoys painted in *red* and *black chequers* will be used to mark rocks in the open sea, also to mark obstructions of small extent having channels on either side of them. When used for the latter purpose, they will be placed to seaward of the danger. Vessels should never attempt to pass between a buoy thus painted and the danger which it marks.
6	Red and white chequers.	When *two chequered* buoys of these colours are used to mark an obstruction, the *red* and *white* one is to mark the *starboard* side of the channel, and must be left on the *starboard* hand by vessels passing in; and the *black* and *white* one is to mark the *port* side of the channel, and must be left on the *port* hand by vessels passing in.
7	Black and white chequers.	
8	Wreck buoys . .	Wrecks will in all cases be marked by *green* buoys, having the word WRECK painted on them in *white* letters; and when a wreck lies in the open sea, or in a position where there is a navigable channel with plenty of room on either side of it, the buoy will carry no other distinguishing mark, and will in every such case be placed to seaward of the wreck. Wreck buoys marked with an *even* number must be left on the *starboard* hand by vessels entering from the sea. Wreck buoys marked with an *odd* number must be left on the *port* hand by vessels entering from the sea. The numbers on wreck buoys will be painted in *white*, and placed above the word WRECK.

[Paper.]

IMPROVED RAPID GROUP-FLASHING LIGHTS.

By Alan Brebner, B.Sc., M.Inst.C.E.

With reference to the three main features of the lightning-light system for lighthouses, one of them, mercurial rotation, was proposed by Fresnel in 1825, and another, the fact that a light produces its full effect on the eye in one-tenth of a second, was experimentally determined by Mr. Swan in 1849. The third feature, the use of broad panels, may, in its separate form, be ascribed to Mr. T. Stevenson in 1855, or perhaps earlier. The combination of these three features in the lightning-light system is due to the late eminent chief of the French Lighthouse Administration, M. E. Bourdelles, doubtless assisted by other very able French lighthouse engineers. These engineers laid down the rule, based on observations at sea, that for every five seconds of time there ought to be at least one of the one-tenth second flashes. That is to say, that the maximum period admissible in practice for the single-flash lightning-light should be five seconds; for the double-flash, ten seconds; for the triple-flash, fifteen seconds, and so on. They asserted similarly that such group-flashing characteristics given in the stated periods would satisfy the requirements of seamen. The system aims at obtaining the maximum possible power, and hence the maximum possible range, from any light-source magnified by optical agents. Before the lightning-light system came out, the Author had frequently urged the desirability of using wider panels than those in current use, notably in 1890, when he proposed the use of trilateral apparatus, a beautiful and probably the first example of which was to be seen last year exhibited in Paris by MM. Barbier and Bénard. The trilateral apparatus was proposed by the Author as the most powerful one capable of being rotated within a lantern of given diameter.

In 1898 Mr. Purves proposed the use of a revolving single-beam apparatus, 180° of lens and 180° of mirror combined with an eclipser, which seemed to promise an improvement on the lightning-light system without eclipser. There are, however, one or two drawbacks to this combination. Thus the light returned from the mirror through flame and lens suffers great loss, so that, instead of giving a beam of twice the power of the unaided lens in front, it only gives an additional power of about one-third when an oil burner is used, and still less with any semi-opaque light-source. Again, this apparatus gives only one flash per revolution. For the high speed of one revolution in 5 seconds, it gives the double-flash group in 20 seconds, instead of 10 seconds, as required by the lightning-light system. Doubtless by using a burner of rather more than twice the usual size, and by increasing the speed to one revolution in 2½ seconds, the desired double-flash in 10 seconds can be obtained. But this involves excessive size of burner, and excessive speed.

LIGHTNING-LIGHT APPARATUS.

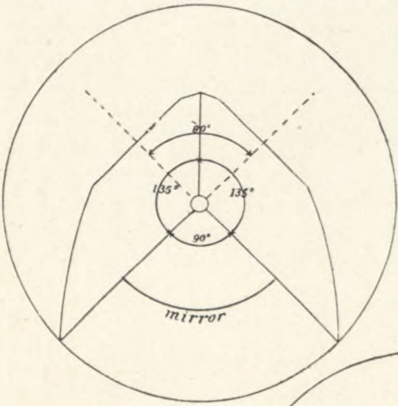


FIG 1
2ble Flash

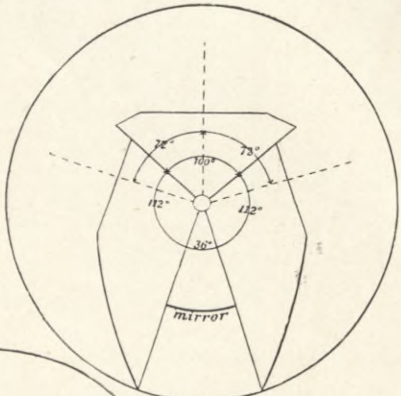


FIG 2
3ple flash

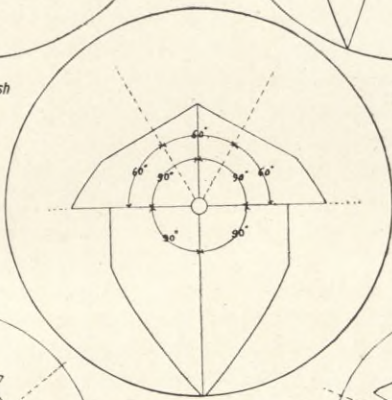


FIG. 3
4ple flash.

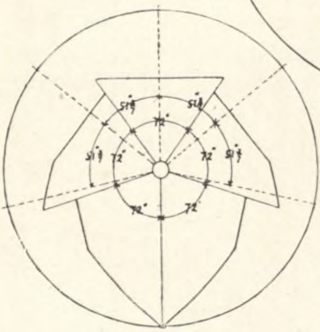


FIG. 4
5ple flash.

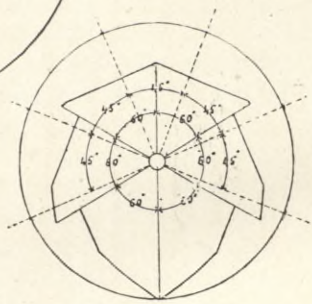


FIG. 5.
6ple flash.

SUB-DIVIDED ECLIPSER APPARATUS.

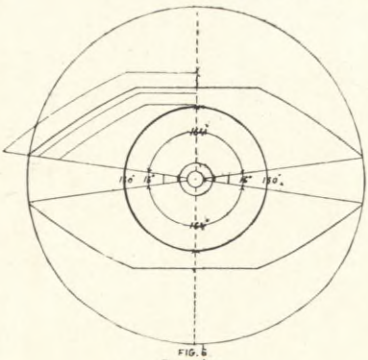


FIG. 6.
Bivalve
All group-flash characteristics

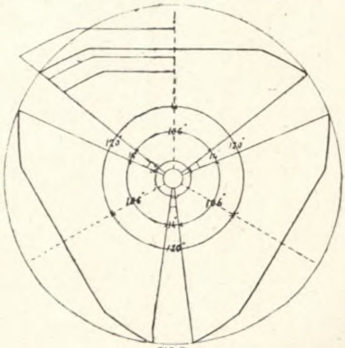


FIG 7
Trilateral.
All group flash characteristics

Mr. Purves proposed also a bivalve apparatus combined with a single complete eclipser. This apparatus, for a speed of one revolution in five seconds, will give the double-flash in ten seconds. But this arrangement can only give satisfactory results at stations where the dark arc is upwards of about 223°·2. This angle is composed of 180°, the angle between the axes of the two lenses, plus 7°·2, the divergence to give one-tenth second duration of flash at the given speed of rotation, plus an angle of 36° within which to raise or lower the eclipser, allowing one half-second for this purpose. Were such a bivalve apparatus placed in a lighthouse with a smaller dead angle than 223°·2, the character of the light shown would not be constant. Very few lighthouses, however, have so large a landward arc as 223°, so that the opportunities of using the bivalve apparatus with undivided eclipser are extremely rare.

To overcome the difficulties inseparable from the single-beam or double-beam apparatus combined with an eclipser, which, alone or along with a reflector, cuts off all the light simultaneously, it occurred to the Author to use a complete subdivided eclipser of two or more parts, each movable independently of the others, along with an optical apparatus of two or more sides. This system requires a screen of two parts for a bivalve apparatus, one of three parts for a trilateral apparatus, and so on, each lens or side of optical apparatus having a screen specially attached to and revolving with it. Each partial screen is made to totally eclipse, when shut, the beam of the corresponding lens. All the group-flash characteristics can thus be obtained from any one of the bivalve, trilateral, quadrilateral, or etc. arrangements, and the flashes can be given more compactly than one per five seconds of total period required by the lightning-light system.

By combining the lightning-light principle with the Hopkinson system of group-flash lights, the power of these has been greatly increased. The Author now proposes to show that by aid of the complete subdivided eclipser, the power of the lightning-light group-flash can in turn be very notably increased. It is admitted that, in a group-flash characteristic, the groups are sufficiently separated by an eclipse three times longer than the eclipse occurring between contiguous flashes of a group. Figs. 1 to 5 represent the most powerful lightning-light group-flash optical apparatus obtainable for double, triple, quadruple, quintuple, and sextuple groups of flashes. In these diagrams dotted lines represent the axes of the flashes, heavy straight lines the inner sides of the dioptric lenses, and curved lines passing through the apices of the obtuse angles of the catadioptric prisms represent the catadioptric portions of the lenses. Allowing that the mirrors shown in Figs. 1 and 2 give one-third increase of power to the opposite angles of lens, the effective horizontal angles of the lenses are seen to be 150°, 112°, 90°, 72°, and 60°, for the double, triple, quadruple, quintuple, and sextuple groups respectively.

Fig. 6 represents a bivalve optical apparatus of the same principal focal length as the apparatus of Figs. 1 to 5, combined with a screen divided into two parts. The effective angle of either lens in Fig. 6 is 164°. This angle is not carried to 180° because the partial screens require to overlap in order that each, when closed, may cut off entirely the light from the corresponding lens. On this account optical agents placed in the extreme angles would be useless. By inserting, however, small fixed screens in the blank angles of 16°, besides using overlapping partial eclipsers, two lenses of 164° effective angle are available. This bivalve apparatus can give all the group-flash characteristics. The same luminaries being used in all the optical combinations of Figs. 1 to 6, the powers are practically proportional to the effective angles. Hence the beams of the bivalve apparatus with subdivided eclipser have the following enhancements of power over the plain lightning-light group-flash beams :—

9·3	per cent.	for the	double flash	(excess of 164° over	150°) ;
46·4	„	„	triple flash	(„ „	112°) ;
82·2	„	„	quadruple flash	(„ „	90°) ;
127·7	„	„	quintuple flash	(„ „	72°) ;
173·3	„	„	sextuple flash	(„ „	60°).

The foregoing figures, however, must be modified if comparison is made of the different combinations designed to revolve within a lantern of given diameter. Thus the apparatus of Figs. 1, 2, and 3 require a larger space to turn in than the apparatus of Fig. 6. Hence apparatus of focal length greater than that shown in Fig. 6 by $\frac{38 \cdot 3}{33}$ will turn in the space required by the combinations of Figs. 1, 2, and 3 ; and the power of the apparatus Fig. 6 would be raised by $(\frac{38 \cdot 3}{33})^2$, or by 1·34. The forenamed advantages of 9·3, 46·4, and 82·2 thus become 47·2, 97, and 145. The combinations, however, of Figs. 4 and 5 turn in less space than that of Fig. 6. Hence the previous figures of 127·7 and 173·3 would be reduced to 101 and 83. When, therefore, apparatus turning in equal spaces are considered, the enhancements of power of the bivalve subdivided-eclipser apparatus over the plain lightning-light group-flash apparatus become :—

47·2 per cent. for the double flash	145·0 per cent. for the quadruple flash
97·0 „ „ triple flash	101·0 „ „ quintuple flash

83·0 per cent. for the sextuple flash.

In Fig. 7, a trilateral apparatus with 3-part subdivided eclipser is shown, of focal length such as to turn in the space required by the bivalve apparatus of Fig. 6. The effective angle of lens available is now 106° out of 120°. When the power of the beams of such a trilateral apparatus is compared with that of the plain lightning-light group-flash apparatus capable of rotating in the same lantern, it is found that the advantage of the former over the latter amounts to :—

85·7 per cent. for the double flash	209·0 per cent. for the quadruple flash
148·7 „ „ triple flash	156·0 „ „ quintuple flash

138·0 per cent. for the sextuple flash.

The foregoing comparisons are applicable with sufficient practical accuracy for all orders of apparatus.

A suitable speed of rotation for the apparatus of Fig. 6 would be one revolution in 5 seconds. Supposing it to be of the third order, the burner sufficient to give a general mean divergence of 7·2° or a flash of $\frac{1}{10}$ second would be the ordinary 4-wick burner of 90mm. diameter, or the improved Trinity 5-wick burner. The quadruple flash would then be delivered thus :— flash 0·1″, eclipse 2·4″, flash 0·1″, eclipse 2·4″, flash 0·1″, eclipse 2·4″, flash 0·1″, long eclipse 7·4″ ; total period 15 seconds.

The trilateral apparatus of Fig. 7 may revolve once in 6″, and the ordinary 5-wick burner of 110 mm. diameter, or the corresponding improved Trinity

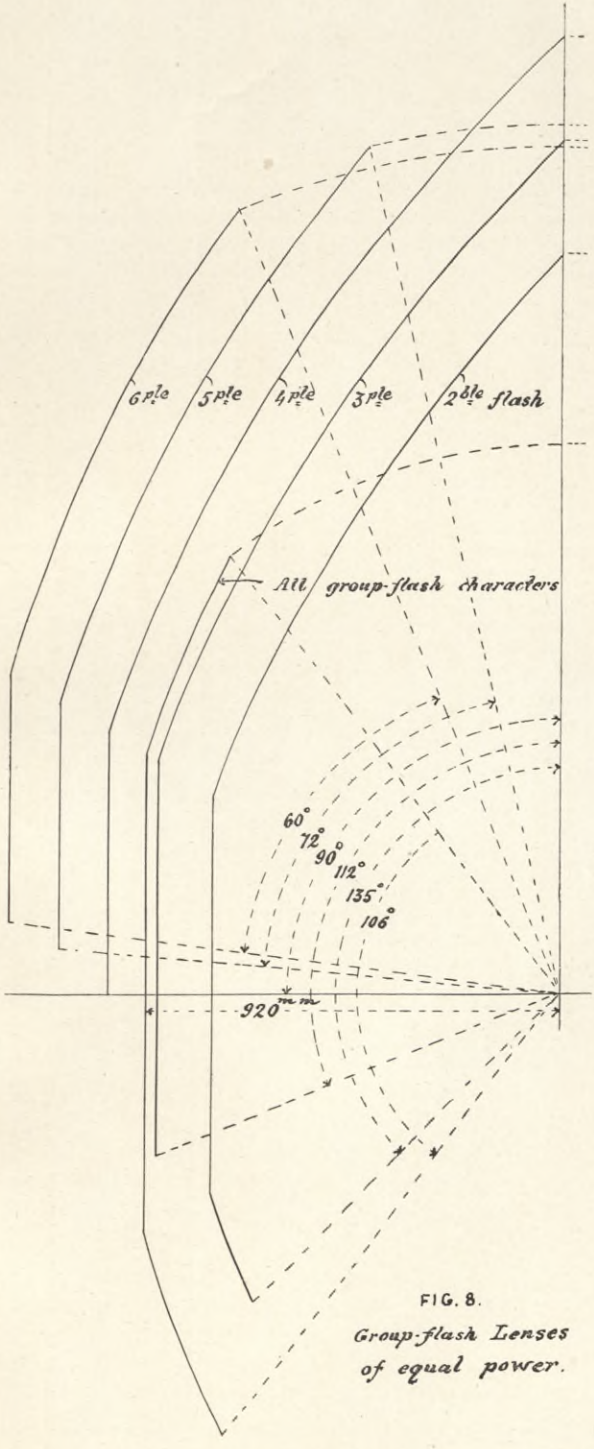
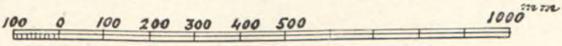
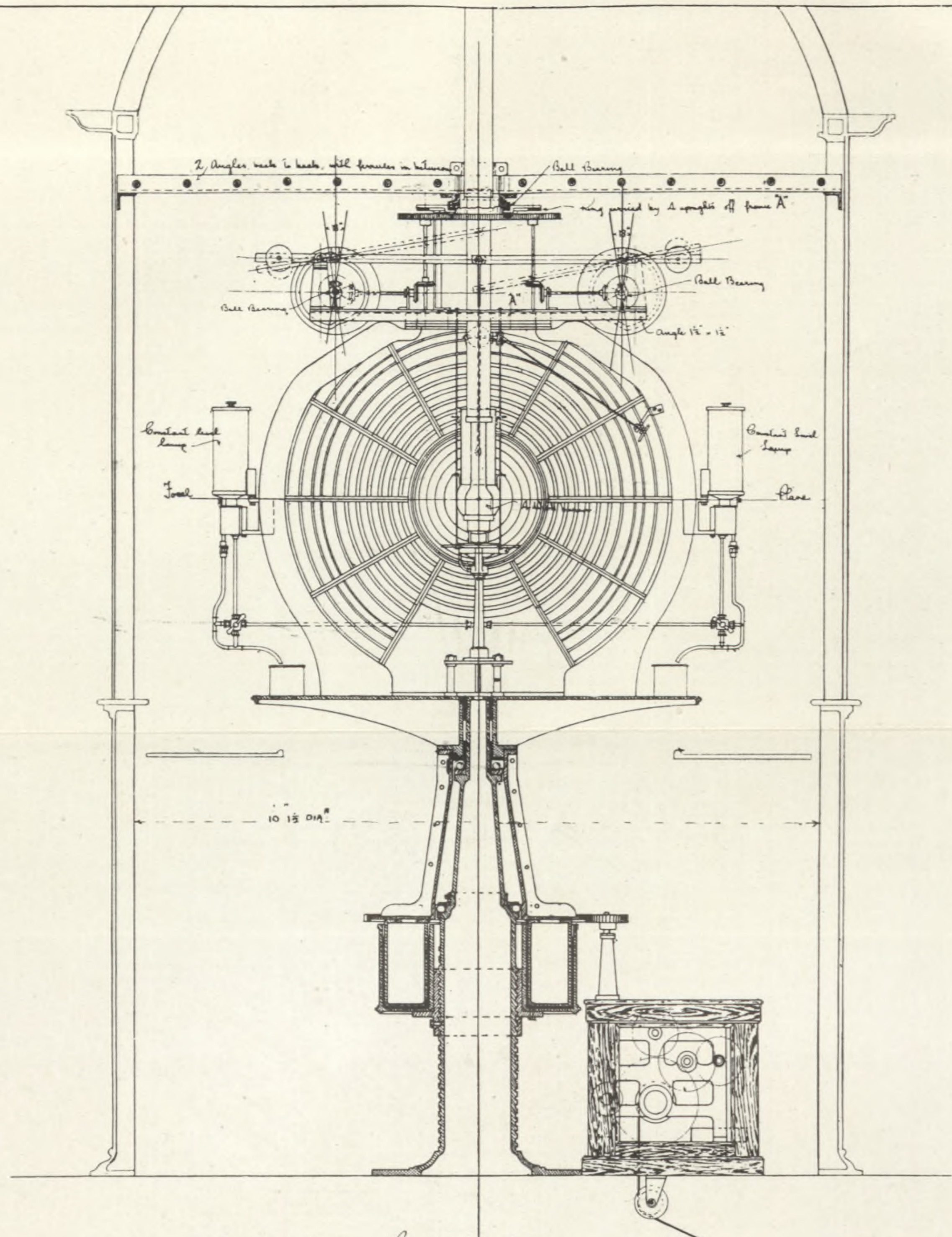


FIG. 8.

Group-flash Lenses of equal power.





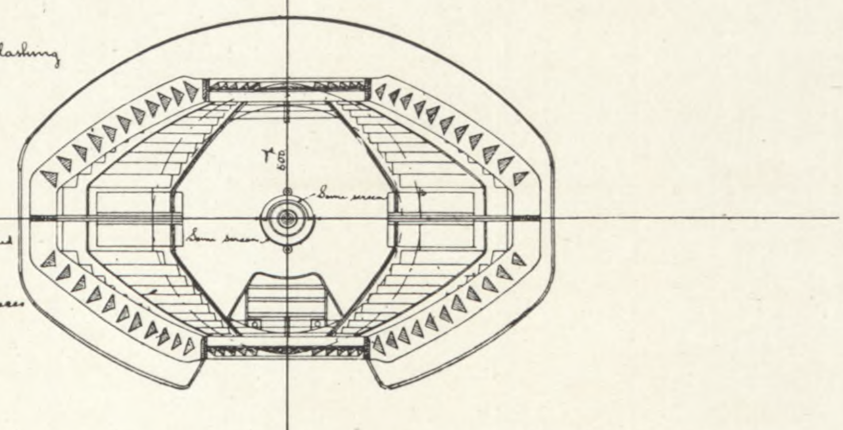
Sectional Elevation

Brebner's subdivided eclipsing mechanism
fitted to 2 sided apparatus for producing double flashing
characteristic as follows –

flash $\frac{1}{10}$ sec
eclipse $2\frac{4}{10}$ "
flash $\frac{1}{10}$ "
eclipse $7\frac{4}{10}$ "

The whole double flashing characteristic being presented in each successive period of 10 seconds

The apparatus makes one complete revolution in 5 secs



Sectional Plan through Focal Plane

2060 Aug 9th 1901

burner, will amply suffice to give a flash of $\frac{1}{10}$ second. The quadruple flash will now be given thus :—flash 0·1″, eclipse 1·9″, flash 0·1″, eclipse 1·9″, flash 0·1″, eclipse 1·9″, flash 0·1″, eclipse 5·9″ ; total period 12 seconds. If the apparatus of Fig. 3 were made to revolve once in 12 seconds with the same 5-wick burner, the characteristic would be :—flash 0·32″, eclipse 1·68″, flash 0·32″, eclipse 1·68″, flash 0·32″, eclipse 1·68″, flash 0·32″, eclipse 5·68″ ; total period 12 seconds. This is no longer a lightning-light characteristic, and the 3-wick instead of the 5-wick burner is quite capable of giving the one-tenth of a second flash in a third-order apparatus, making one turn in 12 seconds. But the comparison shows that in a lantern of given diameter, placed on a tower of given diameter, a trilateral subdivided-eclipser apparatus could be lodged, giving a light three times more powerful than could be obtained from the best plain lightning-light apparatus that could be lodged in the same lantern. Further, this flash of triple power (for it has been shown to be 209 per cent. higher) is delivered on an average once in 3 seconds, permitting of bearings being taken perfectly well. An excellent first-order light, in two groups of four panels, has lately been started at Pendeen. It gives a quadruple flash every 15 seconds, somewhat as follows :—flash 0·5″, eclipse $1·8\dot{3}$″, flash 0·5″, eclipse $1·8\dot{3}$″, flash 0·5″, eclipse $1·8\dot{3}$″, flash 0·5″, eclipse 7·5″. A trilateral apparatus with eclipsers will give about three times more power than the Pendeen apparatus, reducing the duration of flash to 0·17″. The optical apparatus will, indeed, cost more, but not the tower, dwellings, etc. Consequently, a complete view of all the circumstances, in the Author's opinion, shows that in the apparatus represented in Fig. 6, and more especially in that shown in Fig. 7, there lies an improvement important to seamen and appropriate to a time of accelerated speed in ships.

It must not be deduced from anything in this Paper that the Author advocates the use of apparatus of novel focal lengths, but it may be noted that, instead of comparing with the apparatus generally used, others of greater power, involving no extra cost for lantern and tower, it is sometimes better to compare them with others of equal power that can be used with lantern and tower of diminished cost. Each particular case can be efficiently treated by the optical engineer. The foregoing advantages obtainable from the sub-divided eclipser system are substantially real in practice as well as in theory, although it may be necessary in some cases to modify the figures given, which are intended to illustrate the general situation concisely. Full details regarding all orders of apparatus would exceed the scope of this Paper, but the Author will have much pleasure in giving further information to anyone desiring it. The preceding plate, facing page 192, shows a complete third-order optic fitted with eclipser mechanism.

In regard to the working of the eclipsers, trials have been made by Messrs. Chance Brothers & Co. with a view of obtaining a smoothly working and thoroughly reliable mechanism ; and successful results were obtained and exhibited by them last July.

DISCUSSION.

M. Ribière : Je n'ai que trois observations à faire. La première concerne la durée des éclats de lumière. J'ai entendu dire par M. Harding, que les éclats rapides n'étaient pas aussi bons que les éclats longs. Cette remarque serait vraie si les éclats rapides n'étaient pas suffisamment répétés ; mais, quand ils sont espacés par des intervalles inférieurs à 5 secondes, l'expérience prouve que les marins préfèrent le système des éclats répétés. Attendre 30 secondes pour avoir le nouveau signal est trop long. Au contraire avec des signaux suffisamment répétés le marin ne perd pas de vue le gisement du feu, et il peut prendre des relèvements d'une façon continue.

La seconde remarque concerne l'observation émise par M. Stevenson, au sujet de la proposition faite de protéger les côtes par des conducteurs métalliques, placés sous la mer. Un autre système a été étudié depuis quelque temps par l'État français ; c'est celui des ondes Hertziennes. Comme M. Stevenson l'a fait remarquer, les ondes sonores ordinaires ont une portée extrêmement limitée, si puissantes qu'elles puissent être ; parfois elles portent à peine à deux milles. Les ondes Hertziennes, au contraire, ont une très grande portée. Quand les navires seront tous munis de récepteurs permettant de recevoir les ondes de cette nature, il y aura moyen de suppléer à l'insuffisance actuelle des signaux sonores. Malheureusement, quelques navires seulement sont aujourd'hui installés en vue de l'application de ce système, et seulement en vue de communications spéciales ; mais le service des Phares français se prépare à entrer dans cette voie quand le moment en sera venu. Jusqu'ici, pour produire les ondes Hertziennes, on a employé le courant continu et la bobine de Ruhmkorff. Les installations faites au moyen de ce système comportent des organes délicats, tels que les trembleurs, qui sont impropres à assurer le fonctionnement pendant 30 heures au moins, durée que comportent souvent les brouillards. Cela nous a conduit à chercher des installations dans lesquelles nous utilisons les courants alternatifs de nos phares électriques ; on transforme les courants au moyen de doubles transformateurs. Le premier est un transformateur ordinaire ; et le second est un transformateur à haute fréquence, dont les deux circuits sont plongés dans un bain d'huile. D'autres systèmes ont également été étudiés, mais il ne m'est pas possible d'entrer dans la description de leurs détails ; j'ai voulu simplement émettre cette idée que, dans l'avenir, le système des ondes Hertziennes sera capable de suppléer les signaux sonores.

Je voudrais faire encore une remarque concernant la communication faite par M. Brebner. Dans le système des appareils employés jusqu'ici, on divise la lumière en autant de faisceaux qu'il y a d'éclats dans le groupe et on la distribue continuellement sur l'horizon maritime sans aucune perte par occultation. Dans le système Brebner, au contraire, on masque une partie des faisceaux pour produire la grande eclipse. Dans ce système, les panneaux qui produisent les éclats consécutifs sont séparés par un angle plus grand que dans le système ordinaire. L'appareil tourne donc plus rapidement, pour le même intervalle entre les éclats. Il faut par suite employer des brûleurs plus grands qu'il n'est nécessaire dans le premier système ; il devient alors possible de perdre une certaine fraction de la lumière de la source en l'occultant pendant la grande éclipse. La condition pour que ce système soit applicable est donc que l'on puisse facilement augmenter les dimensions de la source lumineuse, comme cela a lieu pour les brûleurs à mèche. Il n'en est plus de même pour la lumière électrique ni même pour les brûleurs à incandescence par le gaz ou la vapeur de pétrole, qui, eu egard à leurs dimensions pratiques, n'ont pu jusqu'ici donner les durées d'éclat voulues qu'en composant les optiques à éclats réguliers de 4 panneaux, même avec des distances focales faibles.

Mr. J. R. Harding : In reply to M. Ribière's remarks concerning the duration of flashes, I am certainly of opinion that 30 seconds is quite the longest interval permissible between flashes, and should only be allowed when the flashes themselves are of considerable duration, and even then such an interval is unsuitable for many sites ; but it is possible to obtain flashes of sufficient length to satisfy mariners with much shorter intervals ; and it is only when the visibility of the flash is reduced to a period so short as from one-fifth to one-tenth of a second, that difficulty is found in obtaining bearings of *single* flashing lights.

I was very much interested in the remarks in M. de Rochemont's Paper of the possible use of acetylene, as I have tried some experiments on a small scale at Shanghai with acetylene in a fourth-order light, with great success as far as they went. I obtained from a Shanghai dealer a small plant, with a burner which he considered to be an 80 candle-power burner, which I tried on several nights; whilst on alternate nights I tried a 72 candle-power mineral oil burner of my own. The results were not comparable, for the nominal 80 candle-power acetylene burner gave at least a 100 per cent. better flash than the 72 candle-power mineral oil burner. The experiments, however, were too short to be considered a really fair trial; but we had no trouble whatever with the burner. The generator was placed outside the tower for safety. One great advantage of the arrangement was that the flame was steady during the entire night, without being touched by the keeper or anyone ; and that is not the case with mineral oil burners. I should like to hear from Baron Quinette de Rochemont what other experiments have been carried out with acetylene, and also his views as to its future.

M. Ribière : Voici les détails que je puis donner en réponse à la question posée par M. Harding.

Il ne s'agit pas d'un appareil à acétylène à flamme éclairante, mais bien à flamme chaude, avec manchons à incandescence. Il y avait là une grande difficulté à surmonter, parce que la flamme la plus chaude est donnée par le mélange d'acétylène et d'air, le plus combustible mélange, dans lequel la vitesse de propagation de la flamme est très grande ; au début la flamme rentrait dans le brûleur, et il y avait détonation. On est arrivé à obtenir des flammes stables avec un système de brûleurs particuliers, dans lesquels la toile métallique est remplacée par un faisceau de tubes de faible diamètre. La température de la flamme étant très élevée, l'éclat du manchon acquiert quatre becs-carcel par centimètre carré, et même six si la pression est assez élevée, au lieu de deux et demi, que l'on obtient avec le pétrole ; et il y a donc là un progrès important.

Les autres détails que je pourrais donner n'ont pas d'importance à côté de celui-là. Les appareils de fabrication d'acétylène que nous construisons sont absolument différents des appareils ordinaires, dans lesquels on s'est surtout attaché à ne fabriquer l'acétylène qu'au fur et à mesure de la consommation. Pour l'éclairage domestique, il peut y avoir intérêt à ne produire l'acétylène qu'au fur et à mésure des besoins. Quant à nous, nous fabriquons chaque jour l'acétylène en quantité suffisante pour faire face aux besoins de la nuit suivante. Nous avons donc un gazomètre qu'on remplit chaque jour, en hiver, parce que les nuits sont longues, et tous les deux jours seulement en été quand les nuits sont courtes.

Mr. C. A. STEVENSON : There is one installation in this country, at Grangemouth, in which acetylene is employed, and it is a perfect success there.

The CHAIRMAN : Is that an incandescent light ?

Mr. C. A. STEVENSON : No, an ordinary burner ; and it burns perfectly.

Mr. N. G. GEDYE : With reference to the adaptation of acetylene gas to lighthouse purposes, I believe an installation has been in use with great success since the winter of 1900-1901, at the principal lighthouse at the entrance to Genoa harbour ; and an incandescent mantle is not used in this case. Several other similar installations have come to my notice.

I should be glad if M. Ribière could say whether he has obtained with his acetylene burner, using an incandescent mantle, the same relative advantage over the non-incandescent flame as he obtains with the incandescent petroleum burner over the old multi-wick lamp.

Baron Quinette de Rochemont mentions in his Paper that the intrinsic brightness of the incandescent acetylene burner is equal to 4 carcels ; whilst with the petroleum vapour burner a value of 25 carcels is obtained. Can he tell us what is the total intensity obtained with the former type of burner, using, say, a 45 mm. mantle ? I believe the 45 mm. petroleum vapour burner, adopted by the Service des Phares, gives an intensity of over 800 candle-power ; is this value in accordance with the latest practice ? Information as to the size of the acetylene burner and mantle, and the total intensity of the flame, would be of interest.

With regard to the question of flash durations, I quite agree with Mr. Harding that many mariners do object to very short flashes—such as one-tenth of a second, common in the French service—more especially when the character of the light is single flashing. The same objections do not hold with double, triple, or quadruple flashing lights, as the flashes forming the group occur in such rapid succession, say at 1½ or 2 second intervals, that the sailor is enabled to take a bearing readily. Theoretically, a flash of one-tenth of a second duration should be employed ; and, personally, I have found that mariners seldom detect the difference in duration between such a one and a flash of a quarter or a half second. I will defy the ordinary seaman who sees a certain light flashing one-tenth of a second, and a neighbouring light giving one-quarter or one-third of a second flashes, to detect the difference between the two durations. The flash of one-tenth of a second is ample to impress itself upon the eye ; the absolute time determined as necessary to impress the retina is about one-twelfth of a second, so that the usual one-tenth is well within the limit.

Turning to the question of mantles for incandescent burners, I understand that Mr. Scott, the Engineer to the Irish Lighthouse Board, has been experimenting with mantles of 50 mm. in diameter, both with Pintsch's gas and with incandescent petroleum. I have recently been connected with an apparatus, intended for Kennery Island, in which it is proposed to use mantles having a diameter of 75 mm., now in course of construction in Paris for the Bombay Port Trust, of which the Chairman of this Section is one of the consulting engineers. A mantle of 50 mm. diameter is being used in the new light for Roker Pier, Sunderland, which is to be illuminated by ordinary coal gas under about 10 inches water-pressure. In the Trinity House service there is, I believe, no incandescent petroleum vapour burner in actual use at the present time. There has, however, been in service at the Low Lighthouse at Lowestoft, for quite two years, a cluster of five ordinary Welsbach burners consuming coal gas. This arrangement, although successful, does not, as will be at once apparent, give any great degree of local compactness, the diameter of the luminous source being large. At the Lowestoft High Lighthouse there will shortly be installed a "Kitson" oil vapour burner,* somewhat similar to the type used in the French service. These incandescent petroleum vapour lights have been in use in the French lighthouse service for quite five years, but it is only this year that they have been adopted by English lighthouse engineers.

Referring to the table of M. de Rochemont's Paper (p. 161), can he tell us the reasons which led to the proposed substitution, at the Chassiron Lighthouse, of incandescent acetylene illumination for the incandescent Pintsch's gas burner installed there in 1895? I observe from the table that the acetylene installation is to be put in service next year. From what I have been able to learn, Pintsch's gas gives extremely satisfactory results, used in conjunction with incandescent mantles. May we take the case of Chassiron as an indication that the French lighthouse authorities consider that the results following the use of Pintsch's gas with incandescent mantles have not come up to their expectations? Personally, I saw several forms of incandescent burners, consuming both gas and vaporous petroleum, in use in Paris during the last year, giving very satisfactory results.

In the same Paper (pp. 167, 168) there is an interesting description of the new light-vessel "Sandettié." I notice that a much larger crew is provided for this vessel than was the case with the two previous vessels of the same class, the "Snouw" and "Talais." I take it that the "Sandettié" is to be moored in a more exposed situation than the previous boats; and it will be interesting to know whether this type, which is decidedly less costly than the Trinity House lightships, gives entirely satisfactory results in situations of great exposure. That question, after all, is one of the most important points in connection with light-vessels.

Referring to Mr. Stevenson's Paper, there seems to be no indication in this that the Pintsch's gas referred to has been used in connection with incandescent mantles. The siren referred to by Mr. Stevenson has been

* Since the date of the discussion, this burner has been placed in service at Lowestoft.

recently under trial at St. Catherine's in the course of Lord Rayleigh's experiments, and I understand that its chief advantage lies in the very sharp admission and cut off which is given to the air, the note being of practically the same intensity from the beginning to the end of the blast.

There is one question I should like to ask Mr. Harding, and that is—What is the flash-point of the oil used in the Hornsby-Ackroyd engines?

Mr. J. R. Harding: With regard to the duration of the flashes, I quite agree with Mr. Gedye that group-flashing gets over, to a certain extent, the objection to the very rapid flashes, and, personally, I am rather in favour of rapid flashes when applied in groups. I was only quoting what was the opinion of mariners, who are sometimes rather conservative; and it is difficult to get them to see the advantages of the rapid flashes. The oil used on the Tungsha Lightship had a flashing point of 250° Fahr.

M. Ribière: Les manchons pour l'acétylène ont 45 mm. de diamètre. Une des difficultés de l'emploi de l'acétylène, consistait au début dans le peu de durée des manchons, qui étaient détruits plus vite qu'avec le gaz ou le pétrole. On y a remédié par une épuration plus complète de l'acétylène. L'intensité totale des manchons a atteint 150 et même 180 becs-carcel.

Quant aux observations concernant les feux à éclats réguliers, nous considérons un intervalle de cinq secondes entre les éclats successifs comme constituant un maximum. Pour les feux importants, nous avons mis des groupes de deux éclats. Cela a été le cas, par exemple, à Ouessant ou à Belle-île. A Chassiron, nous avons annoncé le remplacement du phare actuel par un phare à acétylène. Cela ne veut pas dire que l'ancien système ait donné de mauvais résultats, mais nous voulons faire bénéficier ce feu de l'augmentation d'intensité que permet l'acétylène. En outre, à Chassiron, nous avons à notre disposition une usine à gaz, qui nous permet d'installer favorablement nos appareils à acétylène.

En ce qui concerne les feux flottants, nous avons réalisé un type de faibles dimensions, qui a réussi à l'embouchure de la Gironde, à Talais, mais qui, envoyé prés de Dunkerque, a présenté l'inconvénient d'avoir son pont envahi par les lames à cause de sa faible longueur; c'est pour cela que nous avons fait, pour le "Sandettié," un bateau du même genre, mais plus grand, ce qui exige un plus fort équipage.

The Chairman: The subjects under discussion are extremely interesting, and one might prolong the discussion to a great length; but the time has arrived at which we must adjourn, and I must, therefore, reluctantly bring it to a close. One cannot help recognising the enormous strides that have been made of late years in lighting coasts, and especially since 1874, when the flashing system may be said to have been inaugurated. I remember well that at the meeting of the British Association at Bristol, in 1875, our revered Honorary President, Lord Kelvin, introduced before the Mechanical Science Section the subject of the absolute necessity of differentiating lights, and suggested some combination of the Morse code, by which each light should distinguish itself by spelling its own letter. I recollect, perfectly, that Mr. William Froude, the President of the Engineering Section on that occasion, said he appreciated the idea, which, concisely put, was, to quote Shakespeare, "that every light should name its name, and tell us plainly that it was Snug the joiner." This system has made great strides, owing to the combination of flashes, and I consider it is a subject of the greatest utility.

I have also been greatly interested by the extensive adoption of the incandescent gas burner, and also with the references that have been made to the application of wireless telegraphy and submarine cables. Both systems seem to me to need investigation, because foggy weather and snowstorms are more feared by the mariner than anything else. If any combination of electricity could be introduced to ensure safety, it would be a most valuable step in advance.

The remarks made by M. Ribière and by Baron Quinette de Rochemont, on the observations of the period of the waves, and the design of light-vessels with a view to suitability to the waves at particular places, have interested me greatly, especially as they refer particularly to the branch of engineering in which I am engaged. It is most important that we should all know that observation has shown the period of the greatest wave at a particular place to be more or less a constant quantity, thus enabling the naval architect to design a vessel which will have the minimum of rolling and agitation. That is a point which has been brought before us by the late Mr. William Froude, whose studies in naval architecture were of the most valuable description, and remain a monument to his name.

Mr. D. A. Stevenson replied by correspondence as follows:—

I wish to emphasise the opinion expressed in my Paper that the installation of lights showing a flash of only one-tenth of a second duration is a great mistake, an opinion which is based on repeated observations of my own and the result of a great number of enquiries of mariners and others competent to judge of the effect produced by different durations of flashes. Those who advocate the adoption of these very short flashes should consider really what is implied by the duration of time comprised within the one-tenth of a second. I am perfectly certain that if placed in a position of danger or in doubt on a dirty night, with either rain, haze, snow, or driving spray, they would immediately become convinced of its inefficiency, so far as the necessities of practical seamanship are concerned. It is not at such a time a question of the ease with which the bearings of a light can be taken; it is the question of whether the light can be seen at all or not, and if seen, whether its character can be recognised. It is contended that it is easier to take the bearings of a quickly-repeating light than a slower one; but to take bearings with sufficient accuracy for navigating purposes does not require a rapid period, and is not made easier but more difficult by a short flash. The primary and main considerations for the mariner are that he should see the light at all, and be able distinctly without hesitation to determine its characteristic, which I maintain it is not possible to do with flashes so short as one-tenth of a second, except in fine weather, even although the dark intervals between the flashes be of far less duration than five seconds. Experience has demonstrated that although mariners have no objection to the quick repetition of the characteristic, they prefer at all cost a light with a flash or flashes the duration of which will eliminate all danger of their making a mistake, in consequence of not seeing some of the flashes or not seeing any of them, during bad weather; and the danger is not lessened in the case of a group-flashing light. It has been stated in the discussion that the ordinary seaman is so deficient in intelligence that he cannot see any difference between a light giving a one-tenth second flash and one giving a one-quarter or one-half second, a statement which I have no hesitation in controverting, as look-out men are proverbially quick-sighted; and the remark is certainly not supported by the assertion, which is also made, that one-twelfth of a second is the *absolute* length determined to impress the retina, and that one-tenth second is therefore ample time to impress the eye. I doubt if Mr. Gedye or anybody else would be able to see the difference between the one-twelfth and the one-tenth of a second flash, which is the difference between the "absolute time" necessary and the "ample time" he mentions. If the mariner *saw* the flash *distinctly* for one-tenth of a second it might be sufficient, but that is just the point. The reduction of the length of the flashes to one-half of a second, from the old five to ten seconds duration, originated many years ago in the Scottish lights; but the reduction can be carried too far. A flash of about half a second duration is the least that can be used with safety, and it is for this reason that in Scottish lights the flash has been maintained at about half a second duration.

A great deal has been made of the advantage of a quick repetition of the characteristic, and this is the only argument that is even plausible for adopting very short flashes. I admit that a short period is an advantage, more especially in very narrow channels where the light has to be closely hugged; but on no account even then must the penetrability or visibility of the flash be in the least impaired to attain this quick repetition. In over-sea lights especially, the advantage to be derived from the short period is very small in comparison with the disadvantages and difficulties of manipulation which are introduced to attain the short periods, apart from the disadvantage of the reduced penetrability of the short flash. No one can say that for any single-flash light 10 seconds to 15 seconds, and for group-flashing from 20 to 30 seconds, is too long a period either for taking bearings, or having regard to the distance a ship would travel towards danger during the dark intervals. A vessel travelling 20 miles an hour would only travel, during the complete period, from 110 to 165 yards, which is less than her own length, in 10 to 15 seconds, and from 220 to 330 yards, which is a little more than her own length, in 20 to 30 seconds; and these distances are very small compared with the range of visibility of a light, even in bad weather in any position, and insignificant in the case of over-sea lights. Such periods can be secured with the maintenance of the duration of the flash at about half a second with ordinary burners, which are most suitable for the apparatus employed, and without using any excessive speed of revolution of the apparatus, or intricate appliances which introduce difficulties in the manipulation of the light. This is of far greater moment than some seem to think, as it is of the first importance in an efficient lighthouse that the light shall be maintained at its full power, and show its true characteristic, continuously during the night. Any lighthouse authority, I consider, would be badly advised if they introduced any system which in any way endangers the continuous exhibition of the light; and this the introduction of very rapid revolving or eclipsing apparatus, whereby the lamps cannot be easily got at, inevitably involves. It is, I admit, a matter of minor importance, but, nevertheless, a consideration, that lights of equal candle-power can be produced at a lower cost with such periods and length of flashes as I advocate, than with the *feu-éclair* or *eclipser* systems.

With regard to the use of Hertzian waves as a fog signal in place of submerged cables and induction waves referred to in my Paper, I can only say that there is at present no prospect of the former being able to indicate either the direction or even the distance an observer is from the place from which the signals are sent, and till this can be done they are useless for the purpose. With the cable, on the other hand, these difficulties do not exist.

We have been making experiments in the Scottish service with acetylene for some years, and we have erected complete plant in our experimental yard. We have found that there is no difficulty in the use and working of the plant now manufactured by the better makers, provided that the burners can be attended to every three or four days, and the accumulation of carbon is brushed off them, as this accumulation of carbon destroys the light and causes the flame to smoke. My firm have erected a light and producer for the Caledonian Railway Company, on the acetylene system, on a beacon at the entrance to the harbour of Grangemouth, where it is giving great satisfaction ; and there are several harbour and pier lights on the Scottish coast where acetylene is used as the illuminant. My own experiments were mainly made in the endeavour to introduce acetylene at those beacon lights where it was difficult, owing to outlying dangers, to moor a ship close to, to supply compressed oil gas ; but for use in such beacons we should require a burner to burn continuously for from four to six weeks without attention. As soon as such a burner can be produced, the use of acetylene will be very much increased ; as we shall then be able, in addition to using it in its pure state at beacons by mixing 20 per cent. with our oil-gas, to treble the lighting power of our gas-lighted beacons and buoys at the same cost of maintenance as at present, or otherwise to reduce the cost and keep the power the same ; and no doubt we should be able to burn the same mixture in the incandescent gas lighthouses already established.

I see very little prospect of maintaining an incandescent acetylene burner, owing to the large amount of carbon the acetylene contains, unless, indeed, we could use a forced draught ; but then I fear the mantles would not stand. This I hope to experiment with shortly, though I am not sanguine, as it is not the carbon in ordinary gas that gives the heating power necessary for the incandescent burner. The great benefit to be derived from the use of acetylene is the concentration or the condensation of the flame. A flame from acetylene, compared with an oil-burner of equal photometric power, will only have about a quarter of the area, or, say, half the diameter, and, therefore, the divergence of the beam will only be half that of an oil-light ; this accounts for the penetrating brilliancy of the acetylene compared with oil when used in a lighthouse apparatus, and is in accordance with the well-known fact that the only way of increasing the power of light from a *given apparatus* is by increasing the brilliancy of the illuminant, not by increasing its size. This last may, indeed, increase the photometric measurement of the naked light, but increases very little the penetrating power of the light as seen through a lighthouse lens.

Mr. Alan Brebner replied by correspondence as follows:—

Not having had the opportunity of replying to M. Ribière's remarks on my subdivided eclipser system at the meeting, I send my reply in writing. In the first place, in regard to speed of rotation, I must say that the speed required in this system is well within the limits of what has been accomplished with ease in apparatus now in use. Messrs. Chance could show to anyone desiring it a third-order apparatus working as smoothly and steadily as could be desired. It is only by introducing the idea of small and inextensible luminaries that exception can be taken to my system. Inasmuch, however, as neither incandescent mantles nor oil and gas flames are inextensible, this criticism falls to the ground. I believe that this will be admitted at no distant date by M. Ribière and by any others who may doubt at present the advantages of the system. As compared with the twin-light system in favour in France, which is a more convenient but also a more costly substitute for the old British "biform" system, the subdivided eclipser system will be found to be a conspicuously economical one. M. Ribière has only considered, and that incompletely, the bivalve eclipser apparatus; but the trilateral eclipser apparatus is better than the former. The panels are 120 degrees apart; and the table below shows that, whether for a speed of rotation of 7½ seconds or 6 seconds per revolution, the sizes of burner required are quite normal.

Doty Burners giving One-Tenth Second Flashes in Trilateral Apparatus.

Order of Apparatus.	Speed: 1 Revolution in 7½″.	Speed: 1 Revolution in 6″.
m.		
1·33	6-wick burner.	7-wick burner.
1·125	5 " "	6 " "
·920	4 " "	5 " "
·700	3 " "	4 " "
·500	2 " "	3 " "
·250	1 " "	2 " "
·1875	1 " "	1 " "
·150	1 " "	1 " "

None of the statements made in my Paper have been disproved. The panels of optic being symmetrical on either side of the axis, as shown in Fig. 7, do not at their borders extend so far away from the centre of the lantern as is the case with the ordinary group-flash panels, Figs. 1 to 5. For this reason, supposing the trilateral apparatus to be of the first order, Fig. 8 shows the focal lengths of apparatus, forms 1 to 5, suited to give flashes of equal power, the double and triple flash lenses being reinforced by portions of mirror, as shown in Figs. 1 and 2. Fig. 8 shows also that the ordinary lenses require lanterns of increased diameter as compared with the trilateral, the increase being 820 mm. for the double-flash, 1,340 mm. for the triple-flash, 1,800 mm. for the quadruple-flash, 1,400 mm. for the quintuple-flash, and 1,300 mm. for the sextuple-flash lenses. The lanterns of increased diameter entail towers of increased diameter. Hence arises increase in cost of lantern and tower, roughly, as given on the following table. The cost of the optical apparatus has also to be considered, and it would only be less, with the ordinary lenses, in the case of the double-flash apparatus. A rough estimate of increase of cost of optic is likewise given in the table.

ECONOMY OF FIRST-ORDER TRILATERAL ECLIPSER APPARATUS UNDER ORDINARY GROUP-FLASH OPTICS OF EQUAL POWER.

Character of Light.		2ble flash.	3ple flash.	4ple flash.	5ple flash.	6ple flash.
		£	£	£	£	£
Increase in cost of	Lantern .	360	560	790	620	530
	Tower * . .	440	720	1000	780	670
	Optic . .	- 200	100	310	800	1300
Economy of trilateral . .		600	1380	2100	2200	2500

* Tower supposed thirty feet high.

Of the sums in the last row of the table, a portion would go to cover the cost of the eclipser mechanism, a portion to royalty, the remainder forming a very substantial economy to purchasers. Similar results would hold for other orders of apparatus.

The CHAIRMAN: All I can do now is to express our best thanks to Mr. Stevenson, Baron Quinette de Rochemont, Mr. Harding, and Mr. Brebner, for their valuable contributions on this subject. I wish also to convey, on the part of all present, our great appreciation of the labours of Mr. Vernon-Harcourt, who has worked so hard in giving *résumés* of the papers, and who has so ably fulfilled the post of Honorary Secretary, and contributed in such a large measure to the success of Section II. of the Glasgow International Engineering Congress.

Mr. VERNON-HARCOURT: I must express my grateful thanks to my old friend Sir John Wolfe Barry for the kind words he has uttered with regard to me. I have received so many kindnesses abroad, that I have always felt it my duty, and also my privilege, to do the utmost I could for any International Congress on subjects of which I have had experience; and I thank you all very much for the cordial way in which you have accepted the appreciation of my services, expressed by our Chairman, Sir John Wolfe Barry.

Baron QUINETTE DE ROCHEMONT: Je crois être l'interprète de tous les membres de notre section, en remerciant le bureau, et tout particulièrement son honorable président, pour l'ordre, la méthode, ainsi que la courtoisie, dont il a fait preuve dans la direction de nos travaux; Sir John Wolfe Barry a résumé notamment les discussions d'une manière très intéressante et il y a ajouté des considérations qui tirent un intérêt tout particulier de l'autorité que lui donnent sa haute science et la position élevée qu'il occupe parmi les ingénieurs. Ces considérations ont beaucoup ajouté à la lecture des mémoires et aux discussions.

Je dois également remercier l'honorable secrétaire, M. Vernon-Harcourt—en qui je retrouve un vieux camarade des Congrès de navigation intérieure—pour les exposés qu'il a bien voulu faire au nom de plusieurs rapporteurs et les explications qu'il y a jointes, ainsi que pour son intervention en vue de faciliter les discussions entre des ingénieurs parlant des langues différentes.

Je remercie aussi le comité d'organisation, du choix heureux de ses rapporteurs ; je pourrais dire que tous ont été bien choisis si je n'étais pas l'un d'eux, ce qui ne me permet pas d'en dire tout le bien que j'en pense. En terminant, je remercie encore une fois le bureau, et tout particulièrement son honorable président, Sir John Wolfe Barry, et son honorable secrétaire, M. Vernon-Harcourt.

The CHAIRMAN : I personally thank you very heartily for the kind words you have spoken ; it has been the greatest possible pleasure for me to preside at this Section. My opening words were that I thought it was truly international, and I think it has proved so. We have had the advantage of hearing the views of our French, Spanish, Italian, American, German, Belgian, and Russian colleagues upon matters of the greatest importance to engineering science. I think it is a matter of congratulation that we have been able to associate ourselves here in Glasgow with our *confrères* in every part of the world, to hear their views, and to learn the experience they have gained in their own countries, which we Britishers will lay to heart and derive advantage from in the future.

(*The Proceedings then terminated, and the business of the Section was brought to a close.*)

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BIBLIOTEKA KRAKÓW * Politechniczna

INTERNATIONAL ENGINEERING CONGRESS,

GLASGOW, 1901.

SECTIONAL PROCEEDINGS.

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PROCEEDINGS: Messrs. William Clowes & Sons, Ltd., 32, Cockspur Street, S.W. Price 5*s.* 6*d.*

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LONDON:
PRINTED BY WILLIAM CLOWES AND SONS, LIMITED,
DUKE STREET, STAMFORD STREET, S.E., AND GREAT WINDMILL STREET, W.

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