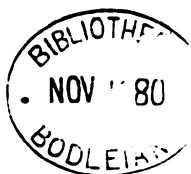


MINUTES OF PROCEEDINGS
OF
THE INSTITUTION
OF
CIVIL ENGINEERS;
WITH OTHER
SELECTED AND ABSTRACTED PAPERS.

VOL. LXII.

EDITED BY
JAMES FORREST, Assoc. Inst. C.E., SECRETARY.



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CONTENTS.



SECT. I.—MINUTES OF PROCEEDINGS.

27 April, 1880.

	PAGE
"The Amsterdam Ship Canal." By H. HAYTER (3 plates, 5 woodcuts)	1
Discussion on ditto (7 woodcuts)	27
Correspondence on ditto	56

4 May, 1880.

Transfer of Associate Members to class of Members	66
Admission of Students	66
Election of Members and Associate Members	66

11 May, 1880.

"The Manufacture and Testing of Portland Cement." By Major-Gen. H. Y. D. SCOTT, C.B., R.E., and G. R. REDGRAVE (2 plates)	67
"Portland Cement Concrete and some of its Applications." By E. A. BERNAYS. (1 plate).	87
"Portland Cement; its Nature, Tests, and Uses." By J. GRANT (1 plate, 33 woodcuts).	98
Appendix: Tables (1 woodcut)	126
Discussion on Portland Cement and Portland Cement Concrete (1 plate, 1 woodcut)	180
Correspondence on ditto (1 woodcut).	208
Resolution to adjourn over Whitsun Tuesday	249

25 May, 1880.

Transfer of Associate Members to class of Members	250
Admission of Students	250
Election of Members, Associate Members, and Associates	250

23 June, 1880.

Conversazione	250
-------------------------	-----

SECT. II.—OTHER SELECTED PAPERS.

	PAGE
"The Practical Strength of Beams." By B. BAKER (4 woodcuts) . . .	251
"Earthwork Slips in the Cuttings and Embankments of various Railways, with their Causes and Modes of Treatment." By J. B. SQUIRE (1 plate)	272
"Earthwork Slips on the Castle Eden and Stockton Railway." H. M. WHITLEY (2 woodcuts)	280
"Earthwork Slips on the Leeds and Wetherby Branch Railway." By H. COPPERTHWAIT (3 woodcuts)	285
"The Seven Stones Light Vessel." By J. N. DOUGLASS (1 plate) . . .	288
"Small Motive Power." By H. S. H. SHAW (1 plate)	290
"Light Draught Steel P.S. 'Terranora,' for Ocean and River Navigation." By J. A. THOMPSON (1 plate)	334
"Notes on the Principal Systems of Electric Light in use in England and in the United States." By K. W. HEDGES	339
Memoirs of Deceased Members	349
General Arthur Jules Morin, 349; John Lawton Haddan, 352; William Johnstone, 354; Edward Tickell Lang, 355; David Llewellyn, 356.	

SECT. III.—ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

Regulations for the Uniform Testing and Nomenclature of Roman Cement.	357
Experiments with Appliances for Testing Cement. A. NOBLE	359
On the Extension of Metals under Tensional Stress after Rupture. J. BARBA	360
Tests of Iron and Steel Shafting. J. HOWARD	361
Report on the Island of Cyprus. L. LUIGI	362
State and Communal Expenditure on Public Works in Italy	365
Report on Belgian Public Works. M. LE HARDY DE BEAULIEU	367
Note on the Port of Cette	370
Repair of the Sill of the Duquesne Lock at Dieppe Harbour. M. ALEXANDRE	372
Clip Calliper for Lifting Waste Weir Planking. A. HAYES	373
The Mulatière Weir on the Saône at Lyons	374
Canalisation of the Meuse between Namur and the French Frontier.	
M. HANS	375
M. de Lesseps' Project of an Interoceanic Canal at Panama	377

CONTENTS.

V

	PAGE
Ice-Breaking in the Vistula. Hr. DÜSING	379
A Storage Reservoir in the Achterfeld. J. G. GAMBLE	380
The Pumping Machinery for the New Waterworks at Hanover. H. BERG	382
On the Causes of the Internal Corrosion of Steam Boilers. M. LODIN	384
Comparative Experiments on Woolf-Engines and Marine Compound Engines. O. HALLAUER	385
Balancing Locomotive Engines. C. A. SMITH	386
Surmountable Gradients. C. BOISSAY	388
The most suitable Dimensions for and Number of the Piers of Iron Railway Bridges	389
On the Durability of Railway Sleepers. Hr. FUNK	390
Central Pacific Railroad Company's Transfer Boat "Solano"	393
Continuous Electric Railway Brake. M. ACHARD	394
Electrical Inter-communication in Trains. G. K. WINTER	394
A Comparison of Different Methods of Colliery Ventilation. J. MAYER	396
Influence of Temperature in Tunnelling through High Mountains. Dr. F. M. STAFFE	399
Warming and Ventilation of the Monge School. S. PÉRISSE	407
Apparatus for Supplying Drinking-Water at the Harbour of Flushing. F. KAPAUN	408
Dervaux's Boiler Feeder. J. HENIN	409
Consumption of Steam in the Rolling of Steel Rails. J. KRAFT	411
The most suitable Diameters for Steam-pipes. H. FISCHER	412
Snow Clearing in Milan. E. BIGNAMI SORMANI	413
Improvements in the Desilverising of Lead by Zinc. C. SCHNABEL	415
The Preparation of Salts of Uranium and Vanadium at Joachimsthal. C. LALLEMAND	417
Schwandorf Continuous Kiln with Gas Furnace	418
The Clearing of Coal Slack by an Air-Blast	419
On the Determination of Phosphorus and Silicon in Iron and Steel. A. E. HASWELL	421
On the Weighing of Steel Ingots during Casting. F. MORO	421
On the Mechanical Equivalent of Heat. Prof. H. A. ROWLAND	422
Sensitive Thermometer for Small Measurements. M. TROUVENOT	424
On Telephonic Effects Resulting from the Percussion of Magnetic Sub- stances. COUNT DU MONCEL	425
A New Form of Constant Electric Battery without Acid. E. REYNIER	426
Comparison of the Power of Hollow and of Solid Magnets. W. HOLTZ	427
Improvement of Siemens Armature. G. TROUVÉ	428
On Electrical Expansion. G. QUINCKE	428

	PAGE
Martelli's Altiplanimetrograph	429
Novel Domestic Motor	430
A Ballistic Apparatus for Registering the Law of Motion of a Projectile. M. SEBERT	431
Note on the Stability of Ships. L. DE BUSSY	432
INDEX	435

ERRATA.

- Vol. xlviii., p. 103, lines 4, 19 and 33, for "*Gatwell*" read "*Gatmell*."
- „ lvi., p. 370, line 1, and p. 371, line 18, for "*Lanbureau's*" read "*Laubereau's*."
- „ lix., p. 190, line 35, for "*James Bower Mackenzie*" read "*John Bower Mackenzie*."
- „ lxi., p. 273, lines 15 and 16, for "*Kusmere*" read "*Kussmore*."
- „ lxii., p. 176, bottom. The figures 215, in test No. 40, column for 13 weeks, on a line with 512, should be on a line with 163.
- „ p. 189, line 20, for "*Professor of Chemistry*" read "*Director or Manager of the Cement Works at Goessnitz*."
- „ the Table, p. 212, refers to Mr. Dyce Cay's remarks on the previous page.

THE
INSTITUTION
OF
CIVIL ENGINEERS.

SESSION 1879-80.—PART IV.

SECT. I.—MINUTES OF PROCEEDINGS.

27 April, 1880.

WILLIAM HENRY BARLOW, F.R.S., President,
in the Chair.

(*Paper No. 1667.*)

“The Amsterdam Ship Canal.”

By HARRISON HAYTER, M. Inst. C.E.

THE Author proposes to describe the Amsterdam Ship Canal, which embraces the construction of the North Sea harbour and breakwaters, and the reclamation of land on an extensive scale, the undertaking being one of the largest and most useful of modern times. The chief object of this canal is to provide Amsterdam, which is situated on Lake Y,¹ an inlet of the Zuider Zee, with a direct and improved deep water communication with the North Sea.

The city of Amsterdam has for centuries been one of the great commercial centres of Europe; but the trade suffered, owing in a great measure to the gradual increase in the size of merchant vessels, the sea approaches to Amsterdam being shallow.

As a remedy the North Holland Ship Canal, from Lake Y, opposite Amsterdam to Nieuwediep, at the Texel Roads, was completed in 1825, previous to which Amsterdam had no communication with the ocean excepting by the Zuider Zee and through the Texel Roads. This canal traverses the low lands of North Holland, and has been extensively used. Its length is 52 miles, its width at the bottom 31 feet, and at the water-level 123 feet 6 inches, the depth being 18 feet 6 inches. An account of this

¹ In Holland this is written Lake IJ. Anglicised it is usually written Lake Y. It is pronounced Lake I.

work was presented to the Institution in 1847, by Mr. G. B. W. Jackson.¹ The rapid increase of trade, fostered by the introduction of railways, and the still growing size of vessels, made it imperative for Amsterdam to provide still better communication with the North Sea. The North Holland Canal also was frequently closed in winter by ice, whilst hitherto it has not been difficult to keep open the Amsterdam Canal, on account of the great traffic and of the large ships that navigate it, which break up ice as it forms.

The distance from Amsterdam to the North Sea, in a direct line, is only 15½ miles, the intervening narrow neck consisting of two shallow fen lakes—Lake Y and Lake Wijker Meer, inlets of the Zuider Zee—and of the belt of sand hills, here about 3 miles wide, which protect the low lands of Holland from the inroads of the sea. This is the route that has been chosen for the Amsterdam Ship Canal, and it may appear strange that it was not selected by the promoters of the North Holland Canal. But at the sea end of that canal at Nieuwediep there is deep water and a quiet sea, whilst at the entrance of the Amsterdam Ship Canal from the North Sea the coast is exposed, flat, and sandy, necessitating the construction of large piers or breakwaters founded on sand, and the formation of an artificial harbour—a work which fifty years ago was considered, if not impracticable, at least too formidable to be undertaken.

Three centuries ago it had been proposed to connect Amsterdam directly by the shortest passage with the North Sea. The proposal remained for a long time dormant, and the idea, although often entertained, was not seriously revived until 1852, when the city authorities appointed a committee, which made a report, allowing fifteen years for the completion of the project; for this reason it was not received with favour. In 1854 the city of Amsterdam announced a premium of 2,000 florins for a design for a North Sea canal which would fulfil the requirements, and especially that concerning the “time of construction;” but the premium was not awarded to any of the ten projects sent in competition. In 1852, two English engineers, Mr. B. W. Croker and Mr. Charles Burn, had, in conjunction with Mr. J. G. Jäger, of Amsterdam, suggested the establishment of a private company for its execution; and on the 17th of April, 1853, the design was presented to the Minister Thorbecke, who received it favourably. But it was necessary to hear the communities interested in Holland on questions affecting the drainage and sea protection, and thus the consideration of the plan was protracted,

¹ *Vide Minutes of Proceedings Inst. C.E., vol. vi., p. 81.*

commission after commission reporting upon it. In the meantime the proposed canal became more and more popular. Memorials were presented to the King, the city of Amsterdam appointed a committee to promote "the canalisation of Holland at its narrowest part;" and in April 1859, the Minister Van Taets appointed a Board of the Waterstaat, by whom the general plan of 1852 was adopted. A project of law authorising the execution, prepared by the Ministers Van Taets and Van Bosse, was withdrawn by their successors, to be followed by new projects, which were also withdrawn. Notwithstanding the manifold discussions and reports, the idea which really became the key of the present undertaking had not yet been put in the foreground, viz., the exclusion of the water of the Zuider Zee from Lake Y, and, of course, from the canal, by a dam or dyke eastward of and shutting in Amsterdam. To leave the canal open to the fluctuating level of the Zuider Zee, to interfere by its construction with the drainage system of the rich regions bordering the Y, while exposing them to danger from which they were before exempt, involved so much that was objectionable, and militated against so many interests, that projects otherwise sufficiently meritorious to receive the sanction of the commissions failed for years to secure legislative sanction. The execution of the dam across a tidal channel nearly a mile wide, involving the construction of an extensive system of locks, sluices, and pumping machinery, is one of the most remarkable features of the enterprise.

By 1861 the difficulties were sufficiently overcome, and in December of that year Mr. Jäger accepted a concession, which was ratified with some modification of details by the law of the 24th of January, 1863, and in 1865 a company was formed for the purpose of constructing the Amsterdam Ship Canal. Sir John Hawkshaw, Past President, Inst. C.E., was appointed consulting engineer, and in conjunction with Mr. J. Dirks, of Amsterdam, the resident engineer, undertook the general control and superintendence of the works. A contract was signed on the 31st of March, 1865, by Messrs. Henry Lee and Sons, of Westminster, for the construction of the whole of the works. The Author has been associated with the works throughout, and Mr. J. Waldorp, of the Hague, locally represented Sir John Hawkshaw, and the following gentlemen on behalf of Messrs. H. Lee and Sons, respectively took local charge, Mr. T. C. Watson, M. Inst. C.E., of the dyke or dam across Lake Y, and of the Zuider Zee locks; Mr. Darnton Hutton, M. Inst. C.E., of the North Sea harbour and breakwaters; and the late Mr Samuel Tate Freeman, Assoc. Inst. C.E., of the works

between Amsterdam and the North Sea Harbour, up to the time of his death at the end of 1871, when his place was occupied by Mr. David Lindsay, and afterwards by Mr. T. C. Watson.

Nearly the whole of Holland is alluvial, the greater part of it being flat, highly-cultivated land below the level of the sea. Along the coast nature has erected an almost uninterrupted barrier of sand dunes or hills, thrown up by the action of the sea, and drifted landward by winds. These sand hills sometimes attain an elevation of 40 or 50 feet, and vary in width from 1 mile to 3 miles. The dunes near the sea are frequently altered in shape by the wind drifting the sand, and where this occurs there is but little vegetable life, but further inland they become tracts of pasture and arable land. At places the sand hills, which would otherwise drift, are sown with plants which take root in such barren soil, especially the reed or helm grass (*Psamma arenaria*). In course of time the roots of these plants spread and consolidate the sand, which thus becomes capable of supporting richer vegetation. A stratum of vegetable soil once formed, portions of the sand hills are converted into pasture or arable land. Besides these dunes, the safety of the country is dependent on the dykes or embankments, by which sea and river encroachments are prevented, and the preservation and upholding of which is systematically organised, and subjected to the strictest supervision.

In order to understand the following description, it is necessary to state that throughout Holland all levels are referred to one datum called A.P., which are the initial letters of the Dutch words "Amsterdam Peil," meaning Amsterdam standard level. By a Royal Decree of the 18th of February, 1818, A.P. is fixed as the basis for the observations of the water heights in the principal rivers of the kingdom of Holland, and even outside the limits of that country this datum is observed. A.P. may be taken to be mean tide level at the North Sea end of the canal, and about high water at the Amsterdam end, where the range of tide is very small.

The following are the correct levels at these places :

North Sea ordinary high water	. .	0·790	mètre (2 ft. 7 in.) + A.P.
" low water	. .	0·850	" (2 ft. 9½ in.) - A.P.
Amsterdam ordinary high water	. .	0·026	" (1 in.) + A.P.
" low water	. .	0·356	" (1 ft. 2 in.) - A.P.

The principal works of the Amsterdam Ship Canal (Plate 1, Figs. 1, 2), besides the earthworks, consist of the dam or dyke across Lake Y, to the eastward, to exclude the waters of the Zuider Zee from the canal, and which is pierced by the Zuider Zee locks and sluices; ¹ of the North Sea locks, ² situated about ¾ mile from

¹ Now called the "Orange Locks."

² Now called the "Ymuiden Locks."

the North Sea, and shutting out the waters of the North Sea from the canal; of the land reclamations intersected by branch canals to maintain existing drainages and navigations, and dividing the reclamations into polders; of the pumping machinery; and of the North Sea harbour and breakwaters.¹ The canal, therefore, consists generally of one long reach between the Zuider Zee locks at one end, and the North Sea locks near the other end, and of a short tidal reach of $\frac{3}{4}$ mile between the North Sea locks and the North Sea harbour. An important stipulation was that the long reach of the canal between the locks at each end is required to be maintained by sluices and pumping at a level of $\frac{1}{2}$ mètre (1 foot 7 $\frac{1}{2}$ inches) below Amsterdam Peil, that is, about 14 inches above ordinary low water of the North Sea, for the purposes of drainage, and for the protection of the district of Amsterdam.

EARTHWORKS.

The cross section of the Amsterdam Ship Canal through the sand hills, and through the lakes Y and Wijker Meer is shown in Figs. A and B (see next page), and for the sake of comparison the cross section of the Suez canal is given in Fig. C, and that of the North Holland canal in Fig. D.

As shown by the cross sections the depth of water of the Amsterdam Ship Canal is 23 feet, and that of the Suez Canal 26 feet. The depth of water in the Amsterdam Canal is fixed, whilst that given of the Suez Canal is the average, and is subject to variation owing to the tide, which although it has a maximum range of only about 2 feet at the Mediterranean end, at the Red Sea end has an ordinary spring range of 3 feet, and an extraordinary spring range of 5 feet 6 inches, which influences the level of the water as far as the Bitter Lakes, or for a distance of 20 miles.

The excavations through the sand hills on the sea margin were the first works commenced, the material being conveyed by wagons or barges, and deposited to form the nucleus of the canal banks through the lakes. The banks are coated with the material excavated from the lakes, and are protected to the extent necessary with fascines. When the sand nucleus was far enough advanced, the deep-water channel of the canal was excavated by dredging, and the material deposited on the banks. The banks are generally 443 feet apart, and their total length is 38 $\frac{1}{2}$ miles. In excavating the canal, ordinary dredging machines were employed at the outset, the material excavated being deposited in barges, and removed by barrows

¹ Now called the "Ymuiden Harbour."

on to the banks. A novel and better mode of delivering the material was subsequently adopted; the material falling from the buckets of the dredger was received into a vertical cylinder fitted to the dredger, in which a Woodford pump 3 feet 6 inches in diameter revolved, and being mixed with a sufficient quantity of water to reduce it to a semi-fluid state, it was forced by the

FIG. A.



FIG. B.

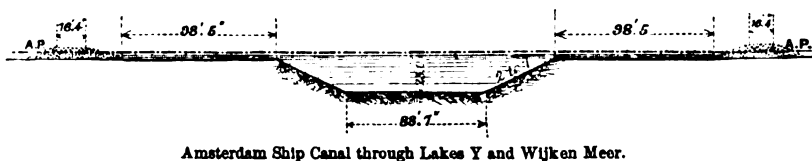


FIG. C.

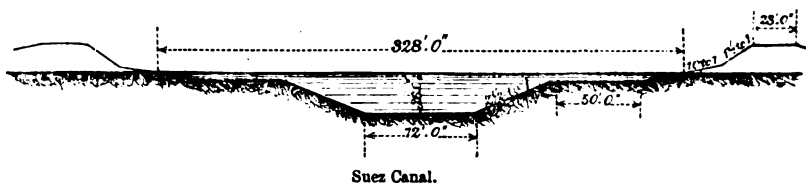
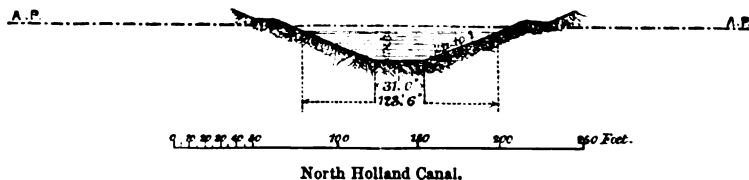


FIG. D.



pump through a line of wooden tubes 15 inches in diameter, connected by leathern joints. These tubes were fitted with buoying pieces to enable them to float on the surface of the water, and passing on to the banks, deposited the stream of mud. The pump, which was driven at the rate of two hundred and thirty revolutions per minute, was fixed to the side of the dredger at the level of the

water; it had a reservoir at the top for the reception of the dredged material, and an inlet at the bottom for the admission of the water, both the openings at the pump being furnished with valves. The longest length of tubes employed was 300 yards, and the greatest height of the discharge above the water has been 8 feet. As the pumps absorb more power than is required to work the buckets in the ordinary way, considerable engine power is required to work these dredgers.

Altogether about twelve dredgers were employed in the excavation of the canal earthworks, to six of which the delivering apparatus was fixed. Two of the most powerful dredgers were made by Messrs. Simons and Co., and the delivering apparatus was designed, and fitted to the dredgers by Messrs. Burt and Freeman. The two large dredgers, under ordinary circumstances, were each capable of lifting and depositing on the banks, through the tubes, about 1,700 tons, or 1,300 cubic yards of material per day of twelve hours, at a cost of about $1\frac{1}{2}d.$ per ton. If the delivering apparatus had not been adopted the time necessary to dredge the canal and to make the banks would have been greatly increased, and the cost also, because, owing to the shallowness of a great portion of the lakes, barges could not in many places have been worked. The wide and shallow berms through the lakes were designed to prevent the banks being injured by the wash from vessels. This they effectually do when overgrown by reeds; the banks only require a slight protection of fascine work until that growth is established. Through the sand hills a more substantial protection, consisting of short piles backed with planks and broken bricks, was constructed near the water level.

The tidal reach of the canal between the sea and the North Sea locks has been still further widened, especially at the end next the sea, so as to form an excellent and well sheltered inner harbour, where vessels can wait to pass through the North Sea locks. This widening has entailed but little expense to the Canal Company, as most of the material has been removed without cost to the Company for the formation of railway and other embankments at Amsterdam.

The profiles of the side or branch canals are generally similar to those of the main canal through the lakes. They, however, are shallower, and of variable depth, and the berms on each side are 20 mètres ($65\frac{1}{2}$ feet) wide, instead of 30 mètres ($98\frac{1}{2}$ feet).

Altogether the quantity of material excavated, including the dredging, in the North Sea to form the harbour has been about 21,000,000 cubic yards.

THE DAM ACROSS LAKE Y.

In order to keep the waters of the Zuider Zee from overflowing and washing away the banks of the Amsterdam Canal, and so flooding the lands drained by it, and also to be able to maintain the water in the canal to the level of $\frac{1}{2}$ mètre (1 foot $7\frac{1}{2}$ inches) below A.P., the dam (Plate 1, Fig. 3) was constructed across Lake Y at a spot about 2 miles eastward of Amsterdam, extending from the existing land dike at Paardenhoek, on the Amsterdam or south side of Lake Y, to the land dike called Waterland's Dike, at Schellingwoude, on the north side, its total length being 1,360 mètres (4,462 feet). In this dam are the Zuider Zee locks, at a distance of 300 mètres (984 feet) from the Waterland's Dike, on the northern shore of the lake. It was at first proposed to throw the dam across at Pampus, considerably further to the eastward, from the lighthouse to Battery Point, where the length, including Buiten Ydorn Polder, across which the dam would also require to have been carried as far as Waterland's Dike (Plate 1, Fig. 2), is 3,500 mètres (11,483 feet), and there the bottom is much worse, so bad indeed that two men boring with a hand auger penetrated to a depth of 50 feet in twenty minutes. The object sought to be attained by placing the dam so far to the eastward was to procure more harbour room for Amsterdam; but the increased length of dam, and the unfavourable character of the bottom, led to this site being abandoned for the present one, although the bottom is not favourable even there, the mud being soft and the material treacherous. To lessen the sinkage, huge mattresses of fascines, about 2 feet 6 inches thick, were laid over the whole breadth of the dam, and were so woven together as almost to resemble basket work. Exterior dams of fascine work were then built to low-water level, the space between them being filled with clay and sand.

The following are the leading dimensions of the dam:—Extreme width at the base about 45 mètres (147 $\frac{1}{2}$ feet); width at the top, 4 mètres (13 feet 1 $\frac{1}{2}$ inch); level of the top at the edges, 3·50 mètres (11 $\frac{1}{2}$ feet) above A.P., rounded in the middle to the extent of 0·15 mètre (6 inches). The outside fascine work at the toe of the bank on the seaward side is laid to a slope of 1 $\frac{1}{4}$ to 1, and the inner fascine work on the canal side to a slope of $\frac{3}{4}$ to 1. Above the fascine work on the outer side there is a slope of 2 $\frac{1}{2}$ to 1 to the level of 0·50 mètre (1 foot $7\frac{1}{2}$ inches) above A.P., a berm of 3 mètres (9 feet 10 inches) broad, and a slope of 3 $\frac{1}{2}$ to 1 to the top. Above the fascine work on the inner side, there is a slope of 2 to 1 to the level of 0·50 mètre (1 foot $7\frac{1}{2}$ inches) above A.P., a berm 5 mètres (16 feet

5 inches) broad, and a slope of 2 to 1 to the top. The slopes, berms, and top of the dam are faced with a layer of at least 1 mètre (3 feet 3 inches) of puddled clay, and both sides were protected from the top to 0.5 mètre (1 foot 7½ inches) below A.P., against the action of the waves by temporary fascines loaded with stones. When the dam was closed, the fascines were replaced on the outside by stone pitching covering the slope from 0.50 mètre (1 foot 7½ inches) below A.P. to the top, and the inside slope from 0.50 mètre (1 foot 7½ inches) below A.P. to the berm. The pitching is nowhere less than 0.30 mètre (1 foot) thick, and is laid on broken bricks 0.20 mètre (8 inches) thick.

The Author would here give a description of the celebrated fascine work, so much adopted in Holland, and known there under the general name of "ryshout," and the mode of putting it together and of laying it in place. But Mr. T. C. Watson, who had the local charge of the dam during its construction and of other works of the canal, has already described very fully this class of work in the "Minutes of Proceedings."¹ It is, however, desirable briefly to remark that fascines under water are nearly always used in the form of "grondstukken" or "zinkstukken," both being made in the same way. The lower zinkstuk is that which reposes on the bottom, hence called "grond" or ground piece. The successive layers are called zink or sinking pieces. It was contemplated at the outset to put two grondstukks under the dam instead of one, but it was considered that it might cause a leakage. The dam, however, actually broke through the one grondstuk in two places, and where this occurred the dam sank vertically, and the lower portion spread out in an irregular manner, the vertical sinking being attributable to a considerable quantity of earth going through the gap in the grondstuk. In one case the occurrence happened suddenly, a portion sinking 2 mètres (6 feet 6½ inches) during the time the men were having dinner, and in the other it took place gradually. In a small length of dam, begun at a later period, a double grondstuk was used, the result being satisfactory.

ZUIDER ZEE LOCKS (Plate 1, Figs. 1, 2, 3, 4).

These consist of three locks, one passage or large sluiceway, and three small sluiceways. Being situated in Lake Y, they were built within a circular cofferdam. The largest lock has a length of 315 feet and is 60 feet wide; the other two locks, one on each side of the largest lock, have each a length of 238 feet and are 47 feet

¹ *Vide Minutes of Proceedings Inst. C.E., vol. xli., p. 158.*

wide. The large sluiceway is 34 feet wide, and the three small sluiceways are each 110 feet long and 13 feet wide. The three locks have each five pairs of gates, two pairs, pointing in opposite directions, being placed at the ends of each lock, and one pair in the middle, pointing towards the Zuider Zee. The sluiceways have each three pairs of gates, two pairs pointing towards the Zuider Zee, and one pair towards the canal. It was necessary before closing the dam to complete and open the Zuider Zee locks for traffic, otherwise the communication between the Zuider Zee and Amsterdam, and places to the westward, would have been cut off. The foundation or memorial stone of these locks was laid by the King of Holland on the 29th April, 1870.

The whole of the masonry and brickwork was founded on bearing piles, upwards of ten thousand being used, and the foundations of the sills and of the lock walls were enclosed in close sheet piling. The three sluices, as well as the powerful pumping machinery fixed upon them, were erected in order to maintain the canal at the prescribed level of 0·50 mètre (1 foot 7½ inches) below A.P., the only other outfall for the rainfall of the district being through the sluices at the North Sea locks into the North Sea at low water. The Zuider Zee locks are on a larger scale than the North Sea locks, it being necessary to provide at the former not only for the traffic to and from the North Sea and the Zuider Zee, but also for that from Amsterdam to the ports on the Zuider Zee. It was incumbent on the Canal Company to enable the shipping of Amsterdam, that would otherwise have been cut off, to get to the North Sea by the Texel Roads instead of through the canal; for although the distance is great, yet the canal tolls could thereby be saved. According to the terms of the concession the locks were to offer ample space for the accommodation of three hundred vessels per day, of such size as, at the date of the concession, traded in the Zuider Zee; but after the work had been contracted for, it was decided to add the third lock. Since these locks were opened it has not been unusual for five hundred vessels to pass through in one day, including small craft, such as fishing-boats; the greatest number registered in twenty-four hours having been six hundred and eighty-one.

In these locks the walls are of brickwork. The Dutch bricks are generally of small size; as a rule they are hard, good, and make excellent work. The hollow quoins, pointing sills, steps, and copings are of limestone ashlar, the stone being obtained from Belgium. The bottom of the lock chambers and the eastern and western aprons outside the gates are of fascine work and basalt pitching. The lock gates (Plate 2, Figs. 5, 6, 7) pointing towards

the Zuider Zee, including those at the south sluice, that is, the sea gates, are of iron; and the gates (Plate 3, Fig. 10) pointing towards the canals, or the ebb gates, as well as the small sluice gates, are of red pine or American yellow pine, creosoted. Iron was considered by the Dutch authorities more trustworthy for the sea gates than wood. The existence of the country being dependent upon the effectual exclusion of the sea, nothing is neglected that in this respect would be likely to add to security, and this also is ensured at the locks by the introduction of additional sea gates.

The lock and large sluice gates are worked by crabs, there being one machine to every leaf for each operation. The gates of the pump sluices are each opened and closed by a wooden lever attached to the gate. In these sluices the bottoms have inverts of brickwork, and provision is made by additional arching and brickwork to carry the pumping machinery and buildings connected therewith.

The mortar is made either of 3 measures of sharp sand and 1 measure of Portland cement, or of 3 measures of Tournay third-class stone lime slaked on the works, 2 measures of Andernach trass, and 1 measure of sharp sand. The concrete is composed of 1 measure of Portland cement, 4 measures of sand, and 5 measures of shingle.

COFFERDAM FOR CONSTRUCTING THE ZUIDER ZEE LOCKS.

This circular cofferdam was 160 mètres (525 feet) inside diameter, and consisted of two concentric rows of sheet piles, with a clear space between them of 6 feet 6 inches. The outer row of piles was of whole timbers sawn to 12 inches wide on the surfaces of contact; but the inner row, excepting the gauge piles, which were of whole timbers, was of piles sawn to 8 inches wide on the surfaces of contact. The timber was Dantzic white pine. The puddle clay between the piles was carried up to the level of ordinary high water, and a mound of sand was deposited on the inside as a counterweight to the pressure of the water. The outer row of piles projected 8 feet above ordinary high water, as at times the height of this ordinary tide level was much exceeded. The inner gauge piles came up to the same level, but the inner row of sheet piles, 8 inches wide, was only carried up to the level of ordinary high water. The walings were arranged as shown in Plate 1, Figs. 5, 6, the lower waling on the inside consisting of laminated timbers breaking joint. The cofferdam would have been more efficient had the inner piles been of whole timbers carried up to the same height as the outer row, and if the upper inside waling

had been made of the same strength as the lower laminated waling. The timbers for the piles, however, were of exceptional length, and so many were needed that it became a difficult matter to procure a sufficient number of the right size; hence it was an object with the contractors to adopt a design which would allow of shorter timbers being used. In order to construct the cofferdam a dolphin was first erected in the centre of the area to be enclosed, the centre pile of which was driven on the 9th of July, 1866. At the commencement some difficulty was experienced in getting the piles of the exterior ring of the cofferdam set out correctly, and it was important for resisting pressure that the cofferdam should be an accurate circle. First, a hempen rope, previously strained, was fastened to the central dolphin, but the rope stretching irregularly, the piles were not true to a circle. Afterwards floating rods were resorted to, but the wind and tide deflected them sideways. At last a light iron wire rope about $\frac{1}{4}$ inch in diameter, kept strained by a weight, was used. For a few days it gave irregular results, but soon acquired its maximum stretch and became sufficiently accurate. It was found, however, that if the guide piles were set out in this manner, as close as 10 feet apart, the resulting curve was not very regular, so they were spaced 40 feet apart. Three pile engines were then set to the curve on a radial lighter, 40 feet broad at one end and 20 feet broad at the other end (Plate 1, Fig. 7), and these drove three piles equidistant in the 40-foot space, leaving intermediate spaces of 10 feet. Three pile engines on the lighter were driven by an 8-HP. engine, with triple purchase gear on to a long shaft. On this shaft were three drums, each of which could be thrown out of gear at any moment.

In order to drive the sheet piles two other lighters were provided, with one pile engine on each, driven by an Appleby steam crab. In every bay the last pile but one was wider at the base, the last being, as usual, a key-pile to close the other piles up. One circular-saw table, driven by a 14-HP. engine, just kept the work going. The ground was of a variable character. Many of the piles could be driven in about ten minutes, whilst others could not be got down without being split, and some could only be kept down by letting the monkey rest on them after the blow had been struck, as they rose 1 foot or 18 inches if the monkey was lifted immediately after the blow. It was subsequently found that this occurred where the layer of peat was thickest and the substratum of sandy clay the softest.

To prevent the ground being scoured on the south side of the cofferdam, where there was at one time an extraordinary current

due to the dam narrowing the lake, long mattresses of fascine work were sunk against the cofferdam. As soon as the cofferdam was pumped dry, the dam, which had then been brought up close to the cofferdam on both the north and south sides, began to push it inwards, distorting the circle by the unequal pressure which had taken no effect as long as the water was inside the cofferdam. The contractors removed some of the clay of the dam to the inside of the cofferdam, but it still continued to move, and the water was let in again, not, however, before the cofferdam had bulged inwards on both sides. More sand was then deposited inside the cofferdam where it had bulged, and the water was pumped out. However, the Canal Company about that time found it necessary to limit the rate of expenditure, so the water was again let in, though not quite to so high a level as outside, to obviate the risk that would be incurred were the cofferdam kept dry. This was done by a siphon, 16 inches in diameter, with a foot-valve outside and a screw sluice inside.

At one time the cofferdam was subjected to a different kind of strain from any which it had been calculated to resist. The water outside, owing to a violent south-west wind, fell to 2·63 mètres (8 feet 7½ inches) — A.P., leaving 2·13 mètres, or nearly 7 feet, head of water inside. An attempt was made to reverse the siphon, so as to run off water from the inside, but this being unsuccessful, the water bent the cofferdam outwards, and the laminated waling as well as the other walings opening at the joints to the extent generally of 2 or 3 inches, but no actual rupture occurred sufficient to cause leakage. These openings in the walings were afterwards filled up with blocks of wood, and when the water was again pumped out, the outside pressure effectually tightened the work. A second laminated waling of four half baulks of Riga red pine was also added just above the original laminated waling, and was secured with 1½-inch bolts to the inside ring only of the piles, in order to avoid increasing the number of through bolts. More sand also was deposited inside, until altogether the quantity reached some 13,800 cubic mètres (about 18,500 cubic yards), or about 27½ cubic mètres per lineal mètre (about 33 cubic yards per lineal yard) of the cofferdam.

At one time, subsequently, the water found its way into the cofferdam and overpowered the pumps. It first made its appearance as a small stream at the bottom of the pump well. By filling the hole with straw, clay, and stones, and depositing sand against the cofferdam on the outside, the leak was stopped; but it soon burst out again in the pump well, a little on one side of the spot

where it first appeared, so to prevent disaster the two sluices in the cofferdam were opened and the water let in. These sluices were about 4 feet long by 15 inches deep, their top being at the level of high water. The sheeting piles of the pump well were at once drawn, and a row of sheeting piles of whole timbers was driven at a distance of 5 mètres (16 feet 5 inches) inside the second ring of the cofferdam across the bad place, and tied to the cofferdam with whole baulks, and 3,600 cubic mètres (about 4,700 cubic yards) of sand were deposited between this sheeting and the cofferdam. Believing that the vibration from pumps working on a stage connected with the cofferdam had an injurious effect, the contractors erected a new pump stage in a position apart from the cofferdam. Not long after, the water was again pumped out, and the excavation for the lock was proceeding, when a huge mass of earth broke off inside the cofferdam at a distance of about 10 mètres (33 feet) from the inner ring of piles, in the line of a small grip which had been made for drainage. The sluices were opened immediately, the water from them being allowed to fall on a bed of fascines laid for the purpose at the spot; however, the ground between where the mass of earth had slipped and the cofferdam soon fell in, leaving the piles bare for a depth of 30 feet, and causing a breach in the cofferdam. An interval of two minutes elapsed from the time the cofferdam first began to bend until the breach opened, and in about three minutes the space inside the dam was filled with water. Seven boats were drawn in by the current, and were swept round the cofferdam with great rapidity. The stream also rushing across the cofferdam, knocked the opposite side with such force as to bulge it permanently outwards. The radial lighter, which was moored inside the cofferdam with four strong $3\frac{1}{2}$ -inch ropes, broke adrift and went down head foremost. No one was injured, but it became evident that the cofferdam needed further strengthening. This was done chiefly by depositing more sand both on the inside and on the outside, and driving a fresh row of close piles on the inside at a distance of 9 mètres ($29\frac{1}{2}$ feet) from the inner of the two concentric rows of piles, to keep the sand in place. Sand-bag buttresses with layers of fascines were also constructed inside the cofferdam where there was sufficient space between the cofferdam and the brickwork. It always proved difficult to keep the sand outside the cofferdam from being disturbed by the wash of the waves. Three groynes of pilework driven on the most exposed side had a useful effect, but the waves still continued to disturb the mound, and it was some time before the contractors could raise it to water level and cover it with fascines.

Much trouble was also experienced in winter from floating ice. Raking round piles were driven outside the cofferdam every 10 feet apart, but they frequently broke when large masses of ice came against them. On one night the drift ice accumulated against the cofferdam with the flood tide until it was level with the top, some pieces of ice being actually pushed over. The cofferdam creaked loudly, but stood the strain without distortion, the water inside being at about 0·50 mètre (1 foot 7½ inches) + A.P. Triangular chocks were spiked at intervals under the outer lower waling, so that the ice might the more readily slide up the waling and not lift it. When the lake was frozen over, the ice was always kept broken around the cofferdam. The result of these precautionary measures and expedients was, that no damage resulted to the cofferdam from ice.

Much of the trouble experienced with cofferdams is occasioned by the through bolts almost always introduced, and this was the case with the cofferdam under consideration. At every high tide there was trouble with leakage at the through bolts placed at the level of 0·45 mètre (1 foot 5½ inches) + A.P., owing to the settlement of the puddle. To remedy this as much as possible every conceivable expedient was resorted to. This leakage tended to disturb the mud and peat under the inside artificial bank of sand.

There can be no doubt that intermediate through bolts in cofferdams should be avoided as much as possible. The puddle sinks and leaves vacuities about them, and although the clay may be well puddled, and when in place well rammed, the Author's experience is, that cofferdams, with through intermediate bolts, invariably leak in a greater or less degree. In some large cofferdams with which the Author has been associated, subsequently to the cofferdam under consideration, for the purpose of constructing the East London railway through the London Docks, intermediate through bolts were dispensed with by Sir John Hawkshaw with marked advantage, and the thickness of the puddle between the rows of piles was reduced to 4 feet 6 inches. Instead of through bolts buttress piles were driven at intervals outside this cofferdam (the inside being strutted) to withstand the pressure of the puddle.¹ Owing to the treacherous nature of the ground at the cofferdam in the Zuider Zee trouble was expected, but an essential element in this cofferdam was its arched form, and as such the abandonment of through bolts and the

¹ *Vide Minutes of Proceedings Inst. C.E., vol. li., p. 151.*

introduction of buttress piles might have been inadmissible. Could through bolts have been dispensed with, and the puddle reduced in thickness, fewer difficulties would probably have been encountered. They were all, however, eventually overcome, and the locks and sluices finished.

THE NORTH SEA LOCKS (Plate 3, Figs. 1, 2, 3, 4, 5, 6).

The North Sea locks are two in number, and there is one passage or sluiceway. One of the locks is 390 feet long and 60 feet wide; the other lock is 227 feet long and 40 feet wide. Each lock is furnished with five pairs of gates arranged as in the Zuider Zee locks. The sluiceway is 34 feet wide, and has three pairs of gates.

The locks are built on sand, which rendered bearing piles unnecessary, but the whole of the foundation of the sills and of the walls is enclosed in close sheet piling. A great deal of water was met with in the foundations, a large spring having been tapped at the westernmost end of the locks. The bottom part of the concrete under the walls, sills, and aprons, was therefore put in place in the form of blocks laid with spaces of about 4 inches, into which concrete was rammed. The remainder of the concrete was carried up in the ordinary way.

As in the Zuider Zee locks, the gates of the North Sea locks, pointing towards the North Sea, are of iron, and the gates pointing towards the canal are of red or American yellow pine creosoted. The design is the same in both places.

The general character of these locks is similar to the Zuider Zee locks, and the materials used in their construction are of the same kind.

THE LAND RECLAMATION (Plate 1, Fig. 2).

An important feature of the undertaking was the reclamation of lands from Lake Y and Lake Wijker Meer. By the formation of the canal a great portion of the area before covered with the water of these lakes has been drained and brought under cultivation. The area intended to be reclaimed was not to be less than 5,000 bunders, or hectares, equivalent to 12,500 acres. The quantity actually reclaimed has been upwards of 13,000 acres, and this has effected a considerable change in the physical features of the country. Lake Y was formerly the recipient of the drainage of an extensive district bordering it, called Rhineland, which includes the Haarlem Meer reclamation, made not many years ago; and

hence the water from Rhineland, or at any rate a great portion of it, has now to be conducted to the canal. This is effected by the branch canals; and that water, as well as the water from the new reclamations, has to be lifted by pumping machinery into the canal. It is to facilitate good drainage and to prevent flooding that the surface of the water in the canal has to be maintained at 0·50 mètre (1 foot 7½ inches) below A.P. A considerable portion of the canal water can be discharged through sluices at the North Sea and Zuider Zee locks at low tides; but the main reliance for keeping the water under is on the pumping machinery at the Zuider Zee locks.

The extent of pumping power to be provided for the reclamations was fixed at the rate of 12 HP. for each 1,000 hectares (2,500 acres), and for each mètre (39·4 inches) in vertical height to which the water has to be raised, and for reducing the level of the water to 1 mètre (39·4 inches) below the lowest level, or surface of the land in each section.

The reclaimed land is divided into twelve polders, the main drains separating the polders being, for the most part, branch navigations. In order to drain the land, main, lateral, and catch drains, with the necessary grips, were excavated or dredged, and it was provided that these together were not to exceed one-fifteenth part of the whole of the land to which they pertained. Plate 1, Fig. 4, represents a reclaimed polder, with the drains and grips.

The following are the different polders and their superficial area, those bracketed being united together for pumping purposes by siphons under branch navigations:—

	Acres.
East Wijker Meer Polder}	
West Wijker Meer Polder}	1,207
East Spaarndam Polder}	
West Spaarndam Polder}	1,305
Houtrak Polder	3,232
Polder III. A	4,125
Polder III. B	1,150
Polder IV. }	
Polder V. }	1,110
Polder VI. }	
Polder VII.	63
Polder VIII.	950
	13,142

PUMPING MACHINERY.

The pumping machinery consists of the extensive system erected at the Zuider Zee locks for keeping the water of the canal at the prescribed level of 0·50 mètre (1 foot 7½ inches) below A.P., and of the pumps for draining the polders.

All the pumps and pumping machinery were made by Messrs. Easton and Anderson of Erith. The pumps are centrifugal, varying in power from 24,000 cubic feet (670 tons) of water lifted 7 feet 2½ inches per minute at the Zuider Zee locks, to 812 cubic feet (23 tons) of water lifted 8 feet 10 inches per minute at Polder VIII.

The general arrangement of the pumping machinery varies considerably, the largest at the Zuider Zee locks having combined pumping engines similar to those erected at Lade Bank, near Boston, Lincolnshire;¹ and the smallest having merely an ordinary case pump, with horizontal fan spindle, driven by a belt.

There are three pumps at the Zuider Zee locks, all precisely similar. The fans have vertical spindles, and are of the double inlet kind, 8 feet in diameter, and 2 feet 11 inches clear depth, with inlets 4 feet 10 inches in diameter, forming waterways of 37 square feet. The fans are driven from the horizontal crank shafts of the engines by mortice bevel gear, proportioned to run the engines at a nominal speed of forty, the fan at seventy-one, revolutions per minute. The crank shafts bridge the pump wells, and are carried by massive A frames resting on cast-iron bed plates, which form frames round the pump wells and support the cylinders, air pumps, condensers, and feed pumps. Each pump is actuated by a pair of cylinders 30 inches in diameter and 2 feet 6 inches stroke, working under 50 lbs. pressure per square inch in the boilers, and cutting off steam by double slide expansion valves at points varying from $\frac{1}{4}$ to $\frac{3}{4}$ the stroke. Expanding four times, the pairs of cylinders would indicate 260 HP. Steam is supplied by eight boilers 23 feet long and 6 feet 6 inches in diameter, each provided with two 2 feet 6 inches furnace flues. The inlet and outlet culverts are 13 feet wide, and from 10 to 12 feet deep; the current therefore has a velocity of somewhat less than 3 feet per second. The mouths of the delivery sluices, or culverts, are closed by self-acting gates, and means are provided for fixing dams to facilitate repairs.

The Houtrak Polder, Polder III.A and Polder III.B, also Polders IV., V., and VI., are drained by pumps of the following general description. The pump cases are built into brick wells; they are of cast iron, each containing a vertical-spindle double-inlet fan, together with the upper suspended bearing of the spindle, the intermediate bearing, and an A frame, carrying the outer end of the steam-engine crank shaft, and the mortice bevel gear by which it drives

¹ *Vide Minutes of Proceedings Inst. C.E., vol. xxxiv., p. 178.*

the fan. The steam engines are horizontal, condensing, and expansive; the air pumps being on the same level as the cylinders, and actuated by the prolongation of the piston rod through the rere cover. Steam is supplied, at 50 lbs. pressure per square inch, by Cornish boilers. The Table (page 20) gives the main dimensions of the pumping machinery, together with the quantity of water pumped per minute, and the height to which it is raised.

The East and West Wijker Meer Polders, and the East and West Spaarndam Polders, are drained by 20-inch case pumps driven by belts, by horizontal engines of the same kind as those above described. Polder VIII. has a pump of the same general form as the other vertical-spindle engines, but with important improvements in the arrangement of the fan, which has only a single inlet opening downwards, the pressure of the water in the pump case being taken by a fixed inlet piece, round which the fan revolves. The stream of water issuing from the fan is received by guide curves, arranged so as to diverge gradually, thereby reducing the velocity of the water without permitting it to eddy and consequently absorbing the momentum in doing useful work.

No attempt was made to introduce steam engines working at high rates of expansion with high pressure steam and jacketed cylinders. It was thought that machinery which would only be used intermittently, and would moreover be placed in isolated positions, and attended by an inferior class of driver, should be of the most simple character. It was important also that the pumps should occupy the smallest possible area, to diminish the cost of the foundations and the buildings.

NORTH SEA HARBOUR (Plate 1, Figs. 9, 10, 11).

The largest adjuncts to the canal are the harbour and breakwaters in the North Sea, forming and protecting the approach from the sea.

The harbour is enclosed by a north and by a south breakwater, each nearly 1,550 mètres (1,695 yards), or together nearly 2 miles long. They shelter an area of about 250 acres, through the centre of which a channel 225 mètres (738 feet) wide has been dredged. At the landward end this channel has at its junction with the canal a guide pier on each side, the northernmost being called the North Mole, and the southernmost the South Mole, each being 335 mètres (366 yards) long.

The north and south breakwaters are similar in design (Figs. 10

Name of Reclamation.	Mean Lift. Ft. Ins.	Mean Quantity to be Pumped per Minute. Cubic feet.	HP. of Water Lifted.	Diameter of Fan. Inches.	Engines.			Number of Boilers.	Boilers.				Size of Engine House. Ft. Ins.	Acres.
					Diameter of Cylinder.	Length of Stroke.	Number of Revolutions of Engine.		Length.	Diameter.	No. of Flues.	Diameter of Flue.		
East Wijker Meer Polder and West Wijker Meer Polder	6 10	903	11·6	28	12½	1 8½	..	1	17 6½	4 9½	1	2 9	..	1,207
East Spaarndam Polder and West Spaarndam Polder	6 10	903	11·6	28	12½	1 8½	..	1	17 6½	4 9½	1	2 9	..	1,305
Houtrak Polder	8 6	2,331	37·4	39	25	2 6	60	1	28 7½	6 6	2	2 6	40·0 × 27·0	3,232
Polder III.A } No. 1	8 10	1,870	32·0	39	19	2 6	60	2	22 11½	6 6	2	2 6	50·0 × 36·0	4,125
Polder III.A } No. 2	8 10	1,870	32·0	39	19	2 6	60	2	22 11½	6 6	2	2 6		
Polder III.B	10 10	1,030	19·5	34	15	2 0	63	1	20 1½	5 9	1	3 0	34·3 × 24·6	1,150
Polders IV., V., and VI.	9 10	1,018	18·8	34	15	2 0	68	1	20 1½	5 9	1	3 0	32·10 × 26·3	1,110
Polder VII. (This small polder has not yet been reclaimed)	..	..	..	..	..	..	..	..	..	..	..	..	..	63
Polder VIII. . .	8 10	812	14·1	32	13	1 9	62	1	20 1½	4 8	1	2 6	34·3 × 24·6	950
		10,737	177·0											13,142

and 11). They were built on a very unfavourable foundation, consisting of very fine sand.

The Author has previously given to the Institution a brief account of these breakwaters,¹ and the plan of foundation which finally answered. It was attempted in the first place to construct them by a staging of screw piles, but a slight disturbance of the sea excavated a hole round the piles, laying them bare or sufficiently so to destroy the staging. This plan was abandoned, and it was then tried, after partially excavating the sand, to set the concrete blocks by an overhanging travelling crane which was to advance on the pier as the work was brought up. It was hoped that when the bottom blocks had been set they would, notwithstanding the disturbance of the sand, form a bed which could be levelled and upon which the structure could be raised. This mode of procedure did not answer. It was then determined to substitute for the bottom course a layer of loose material consisting for the most part of basalt from the Drachenfels and limestone from Belgium, thrown in as random work. This was the plan finally adopted to secure a foundation. The mound of stone was deposited about 1 mètre (3½ feet) thick, and to a width about three times that of the pier at the base, so that when, by the disturbance of the sea, a trench was excavated at the sides of the mound, as was always the case, the loose deposit fell into the hollow until the normal slope was attained (Plate 1, Figs. 10, 11), leaving a central portion upon which to build the pier. By this plan, when the piers advanced, the trench, which in places had been no less than 14 or 15 feet deep, gradually filled up. The stones of the deposit varied in size from about 1 cubic foot and under. In levelling the deposit for the reception of the first course of blockwork, the interstices were filled with hard broken bricks, big shingle, or stone broken to sizes of about 3 inches square. When possible the deposit was exposed for twelve months to the action of the sea before being built upon, by which time the surface became covered with mussels, and was very hard, so that it was difficult to disturb it by iron bars or otherwise.

The concrete blocks, of which the chief portion of the solid structure of the piers is composed, varied in weight from 6 tons to 12 tons, and were made of 1 measure of Portland cement, 3 measures of coarse river sand, and 5 measures of shingle, the sand being obtained from the Rhine at Vreeswijk and the shingle being dredged from the Rhine, chiefly in the neighbourhood of Nymegen.

The concrete blocks were put in place for the most part by

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. xliii., p. 34.

powerful overhanging travelling cranes, there being one such crane or "Titan" to each breakwater. Several designs of Titan were tried, which generally answered very well; but the north breakwater being more exposed, it was decided after the works had been considerably advanced and two Titans had been swept away, to employ a steam travelling crane, which was run out to its work by a locomotive engine, and brought back every evening for security in case of storms.

The rubble deposit was levelled and the blocks under water laid by divers. Laying the blocks was much facilitated by the use of a self-disengaging apparatus designed by Mr. Hutton. Below low water the blocks were set dry, but above low water they were set in Portland cement mortar, and were well cramped together. The upper portion of the structure was formed of concrete *en masse*.

The pier heads are square with rounded corners, and are 1 mètre ($3\frac{1}{4}$ feet) higher than the adjoining length of pier, which slopes up to the head with a gradient of about 1 in 100. The heads are in line with the piers on the seaward side, but on the harbour side they have a projection of 6 feet.

The concrete mixers were designed by the contractors, and answered perfectly. Similar mixers had before been used by Messrs. Lee in the construction of the Admiralty pier at Dover.

When the piers were originally designed, the information supplied as to the rise of the tides was inaccurate, the tidal range being at times much greater than was then assumed. Partly in consequence of this, the design proved too near the margin of safety for a sea work, and when the breakwaters were considerably advanced seawards, the "wave-breaker" on the sea side was added. The extent of the wave-breaker on each breakwater is shown in Plate 1, Fig. 9. It begins about 100 mètres (328 feet) nearer the coast-line on the north breakwater than on the south breakwater, on account of the former being exposed to seas somewhat heavier than the latter. Gales of wind affecting the breakwater begin from the south-west and strike upon the south breakwater, and almost invariably end from the north-west, striking on the north breakwater, the latter part of the gale being generally more destructive than the former.

The wave-breaker consists of concrete blocks deposited *perdue*; the weight of the lower blocks is about 10 tons, and of the upper blocks 20 tons. These blocks are disturbed by the sea until they form a slope of about $1\frac{1}{2}$ to 1.

The interior moles are constructed of fascines, broken bricks, and stones, following a mode common in Holland.

The dredged channel in the harbour has a bottom width of 225 mètres (738 feet), and a depth varying from 8·50 mètres (27 feet 10½ inches) below A.P. opposite the pier-heads, to 7·50 mètres (24 feet 7½ inches) below A.P. at the north and south moles, which is the depth of the canal. The quantity of material originally intended to be dredged amounted to about 1,800,000 cubic mètres (2,350,000 cubic yards); but owing to the necessity imposed by the authorities of prosecuting the dredging before the breakwaters were finished, and the enclosed area made quiescent, and owing to some materials from the excavations of the canal being carried into the harbour, the quantity dredged has amounted to about 4,000,000 cubic mètres (5,230,000 cubic yards), which had for the most part to be taken out to sea and deposited at a minimum distance of 3,000 mètres (3,300 yards) from the coast-line.

The machines used for removing this large quantity of material were principally sand pumps designed and arranged by Mr. Hutton, and worked by steam engines (Plate 3, Figs. 7, 8, 9). The sand pump consisted of a centrifugal pump with a fan 4 feet in diameter, and with suction and delivery pipes each 18 inches in diameter attached to an open wrought-iron framework. The machine was suspended between guide timbers fixed to the end of a vessel, and was free to follow the movement of the vessel, which was fitted with tackle for raising, lowering, and adjusting the machine. The vessel contained the steam engine and boiler for working and manipulating the pumps, and the head and side chains for the guidance of the dredger. The engine was of 70 HP., made by Messrs. Maudslay, but was seldom worked above 55 HP.

The cost of each sand pump, with engine, vessel, and appliances complete, was about as follows:—

	£
Vessel, steam engine, boiler, and sand pump complete . . .	5,000
Two barges with each machine for the reception of the material, at £1,000 each	2,000
Steam-tug for towing barges to sea = £2,000, but as this served for two sand pumps, for each	1,000
Total cost for one machine	<u>8,000</u>

The number of hands required for the sand pump were one captain, one engineer, one stoker, and four sailors; for the two barges two men each; and for the steam tug five men. As this latter served for two sand pumps, it was equal to two men and one-half per machine, so that the average for each machine was thirteen and a half hands. The consumption of coal was about 1½ ton per day for each machine.

When at work the suction pipe tended to bury itself in the

sand, being held by the lifting chain at the most effective point, which was generally found to be from 3 to 4 feet below the surface of the ground. Each machine was capable of raising about 1,300 tons of material per day, the engines working at 60 and the pump at 180 revolutions per minute.

The cost of raising the material and of depositing it in barges was somewhat under one penny per ton when the sand pumps were working, but as the number of working days in the year averaged only about 150 this cost was much exceeded. But few repairs were needed. Twelve of the machines were at work up to the 1st of January, 1877, when the Canal Company took the dredging into their own hands, still continuing the use of the sand pumps. They afterwards added some ordinary bucket dredgers, one being a large dredger hired from the River Tyne Commissioners with two steam hopper-barges, the original cost of which was about £40,000, and which required to work it eighteen men in the dredger and eight men in the steam barges, being four men to each barge. The cost of raising the material with the bucket dredgers was certainly more than with the sand pumps. In addition to sand, some silt was met with of so fine a character that it did not settle when pumped into the barges, and it was accordingly removed by the bucket dredgers, although probably some arrangement might have been contrived to utilise the sand pumps for silt as well as for sand.

The width of the entrance between the built blockwork of the breakwater heads is 260 mètres (853 feet); but the navigable width is not above 200 mètres (656 feet), on account of the blocks of the wave-breaker. The available space, however, affords room for easy access to the harbour. The currents at the entrance and inside are of the usual kind in harbours similarly situated. They run parallel to the coast, and therefore across the harbour mouth, the flood current being the stronger. This flood current runs north, and being barred by the south breakwater causes some accumulation of water, which flows off along the breakwater. After passing the bend of the breakwater it sets a little in the direction of the outer wing or kant, bending again towards its normal course and partly flowing into the harbour and along the inside of the north breakwater with diminishing speed, and across the inner moles, is lost in the southern part of the harbour. The ebb current is less powerful, so that there is no current across the moles. The currents, both flood and ebb, are somewhat weaker with the wind from the shore, there being then less accumulation of water along the coast.

During the flood vessels enter the harbour close to the south breakwater, and during the ebb close to the north breakwater. The harbour instructions direct attention to the fact that the forepart of a vessel reaches beyond the tidal current even before it gets between the breakwater heads, whilst the afterpart remains exposed to its full force. With a strong flood a velocity of 6 miles an hour is necessary to enter the harbour. Not being sufficiently acquainted with the force of the current, or not being able to get enough speed, or with a ship that works badly, it is advisable to await high water, which is signalled from the semaphore station on the shore. After passing the heads the speed of the vessel should be slackened to 4 or even 3 miles an hour, so as to approach with care the end of the moles, which are about 1,000 mètres (1,094 yards) from the entrance. Inside the moles there are mooring posts where ships can be stopped, moored, or manipulated. In entering the harbour it is almost always desirable for sailing vessels, unless they be small, to engage a tug. For steam vessels the entrance offers no difficulty.

The channel of the canal between the north and south moles and the North Sea locks being well sheltered by the sand hills, and enlarged as before remarked, forms an excellent basin for ships intending to pass the locks to Amsterdam.

CONCLUDING REMARKS.

In describing works it is always desirable to give their cost. In the case of the Amsterdam canal it is not easy to do so with precision, inasmuch as, owing to necessary financial arrangements, the cost of the work was much enhanced beyond that due to the actual construction.

The following is the contract sum for the several works, or rather the assumed equivalent money value of the cost of the works :

	Florins.	Florins.
1. Piers	9,644,965	
Wave-Breaker	3,341,170	
		12,986,135
2. Harbour Dredging		1,401,203
3. Excavations and Dredging in Canal		9,049,648
4. North Sea and Zuider Zee Locks pumping engines and Velsen Bridge.		4,208,975
5. Dam across Lake Y		1,208,732
6. Protection to slopes		259,200
7. Channels to Zuider Zee Locks		65,237
8. Land reclamations		1,484,600
9. Towing paths		306,400
10. Mooring posts		84,240
11. Lighthouses		26,800
		31,081,170

There are 12 florins to £1 sterling, so that the above total sum is equivalent to £2,590,097. Besides this expenditure in the works the company spent various sums of money, and altogether the cost of the canal has amounted to somewhat under £3,000,000, without taking credit for the sale of the reclaimed land, which realised on an average about £70 per acre. The cost of the work in detail was also influenced by financial arrangement, but it may be stated that the price of work in Holland differs but little from rates paid in England; for though labour may be somewhat less costly, most materials are somewhat dearer.

The canal is spanned by three swing bridges. Two of these are near Velsen, one bridge carrying the Holland railway across the canal, and the other a roadway. These bridges are only a short distance from each other. The third bridge is situated near Zaan-dam, and carries the States railway from Amsterdam to the north across the canal. All these bridges are of one type common in Holland when headway can be obtained, the arms of the swing portion being of equal length, and the roadway being on the top of the superstructure, which turns on a long central pivot passing through to the underside of the roadway platform.¹

The canal was opened for traffic on the 1st of November, 1876, by the King of Holland. The contract having been let to Messrs. Lee in 1865, twelve years elapsed before the undertaking was completed, a longer time than would have been necessary had it been possible to prosecute the works without interruption. Financial and other difficulties, and protracted negotiations impeded operations. The keys of the work were the North Sea breakwaters, and the construction of these would doubtless have absorbed the greater part of the time; but the canal might have been opened before this portion of the work was completed.

From the outset a large traffic has passed through the canal, and this is rapidly increasing. It is encouraged by low rates, which are raised chiefly to meet the cost of maintenance and repairs, as the Dutch Government guarantees interest on a portion of the expenditure. Indeed, the undertaking is of such advantage to Holland in general, and to Amsterdam in particular, that in all probability the navigation will shortly be made free to all the world.

The Paper is illustrated by numerous drawings, from which Plates 1, 2 and 3 and the woodcuts have been engraved.

¹ *Vide Minutes of Proceedings Inst. C.E., vol. lviii., p. 40.*

Discussion.

Mr. HARRISON HAYTER desired to thank Messrs. Easton and Mr. Harrison Anderson for having prepared and furnished him with drawings of the pumping machinery, and also with the Table embodied in the Paper, giving the details of the pumping machinery of the Hayter.

FIG. 1.

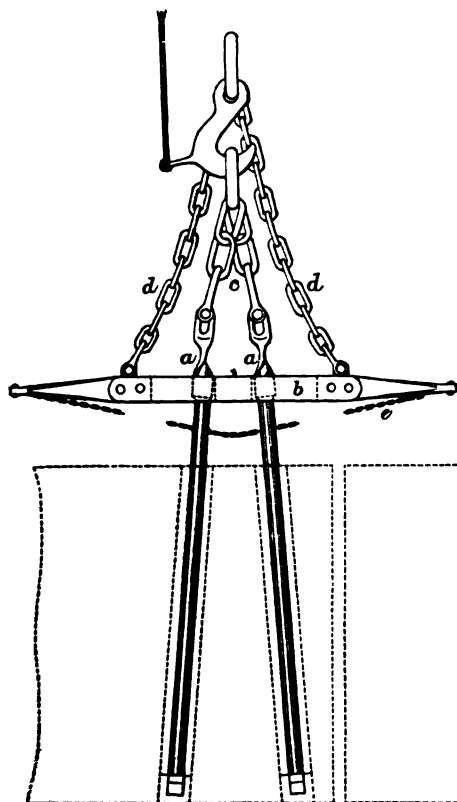
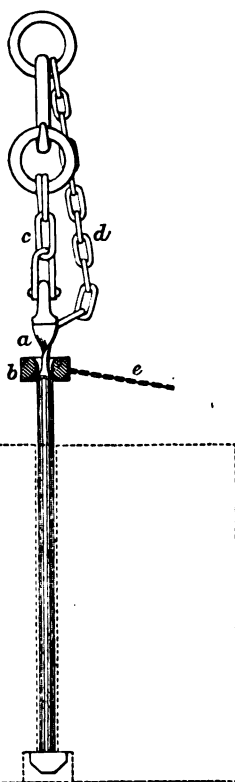


FIG. 2.



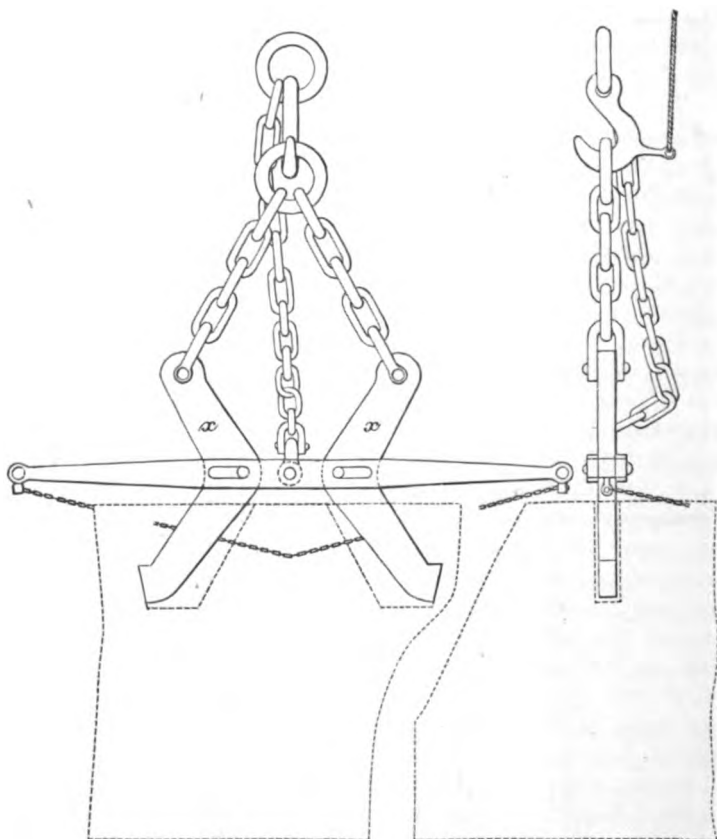
land reclamations. The particulars of the cost of the works were not quite so full as he should have liked to have made them. It had, however, been difficult to arrive at this information, as the works had been hampered by financial complications and protracted negotiations. With reference to the lock gates, of which it would

Mr. Harrison
Hayter.

be observed there were no less than forty pairs, including the sluice-gates, the question of such gates had been discussed so recently¹ that he would only allude to peculiarities connected with the lock gates of the Amsterdam ship canal, which were

FIG. 3.

FIG. 4.



departures from the practice usually followed in this country. It was stated in the Paper that the gates pointing towards the sea were of iron, and those pointing towards the canal were of wood; and reasons were given why they were so made. That opened up the question as to the comparative merits of those two kinds of

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. lviii., p. 154, and lix., p. 2.

material for lock gates; but the subject had been alluded to in the course of the discussion referred to. There were three departures from the practice usually followed in this country in the lock gates of the canal. The first was in the method of forming the water-tight joint between the gate and the masonry at the hollow quoin, which in this country was usually done by the contact and accurate fitting of the heel-post of the gate with a portion of the surface of the circular hollow quoin. It was difficult to make such a joint quite water-tight, and there was generally some leakage. The method adopted in the gates under consideration is shown in Plate 3, in which an iron gate is represented as closed. The water-tight joint was made by a vertical piece of timber attached to the heel of the gate shutting against a vertical projection about 8 inches wide on the stonework, which was polished from top to bottom. The gate cleared the circle of the hollow quoin, excepting in the line of thrust, which was communicated to the wall also by the interposition and accurate fitting of a piece of timber about 8 or 9 inches wide. The plan was effectual, but a little more costly than the one usually adopted, inasmuch as the stone projection at the water-tight joint being clear of, and on the water side of, the circle of the hollow quoin, it rendered it necessary to bring the wall more into the lock, so that there was a somewhat greater thickness of masonry or brickwork than would otherwise be required. If the heel-post of the gate were of wood and was not of iron, the heel-post would shut and thrust direct against stone projections, the interposition of pieces of timber being then unnecessary. The second departure was that the gates turned on pivots placed a little out of the centre, so that immediately the gate was moved it cleared the hollow quoin, and thus there was a relief from friction. On the other hand, it left a space round the hollow quoin, and loose material might get in between the heel-post and the wall, in which case the gates might not close with the required accuracy. The third departure was that there were no rollers in connection with the gates; but on this point he had given his views previously.¹ He wished to draw attention to an ingenious apparatus invented by Mr. Darnton Hutton, which was extensively used in setting the blocks at the North Sea breakwaters, and which was shown in Figs. 1 and 2. The apparatus consisted of two round bars with T ends. At the neck *a* of the bars there was a twist, of a quarter turn. The bars were placed into oblong holes with

Mr. Harrison
Hayter.

¹ *Vide Minutes of Proceedings Inst. C.E., vol. lix., p. 4.*

Mr. Harrison
Hayter.

square ends made in the blocks, and there was a cross bar *b*, which, when down, gave the quarter turn, when the block could be lifted by a chain *c* attached to the top of the two round bars. When it was desired to disengage the apparatus, the chain *d*, attached to the cross bar *b*, was pulled up, and it raised the cross bar, which, giving the quarter turn to the round bars and T ends, enabled the apparatus to be lifted out. To another chain *e*, at the extreme ends of the cross bar, a rope or small chain was attached, so that the block, when suspended, could be slewed into any position. There was another contrivance, Figs. 3 and 4, generally on the same principle, and also extensively used, but in which, instead of two vertical bars, there were two nippers *x*, which, when the block was lifted by the chain, pressed tightly against the side of the holes in the block, so that it could be raised. He had shown these contrivances in justice to Mr. Hutton, who did not care to exhibit them himself, and he did not think the Paper would have been complete if he had not described them, inasmuch as they were useful, saved cost, and facilitated the setting of the blocks.

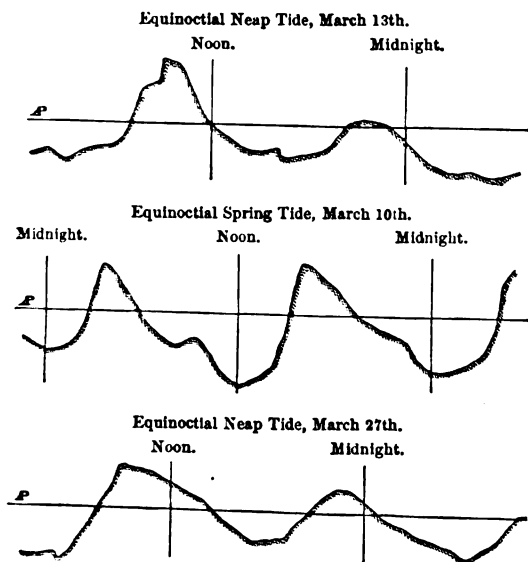
Mr. Watson.

Mr. T. C. WATSON said he could only speak of those parts of the work which had come under his own supervision—the dam and the cofferdam, with regard to which there had been a full discussion on the disasters that arose at various times during the construction of the locks. It had been correctly pointed out that the chief source of the misfortunes was the bolts. The infirm and treacherous ground had caused the puddle to sink, and there was a continual leakage from below the bolts. The attempts to combat with it were of no use, and it became necessary to remove the bolts entirely, and put them up above the flood-water, introducing a third ring, and immensely increasing the amount of sand, to resist the pressure of the water. There were all sorts of devices besides. Of course it was to the advantage of the Institution to know the faults in the original design, and how, if the works had to be carried out again, those faults would be remedied. There was one peculiarity about the works to which the Author had not adverted. None of the plans were designed at the time of taking the contract. A lump sum had been put down for the North Sea locks, and other lump sums for other things, and the best had to be done for the money. Cheapness had to be studied as much as possible, having regard to the interests of all concerned, especially the contractor, whom he represented, and perhaps the tendency was a little too far in that direction. If the works had to be made over again, no doubt an immense number of improvements would be introduced. Too much reliance was placed on the circular

form; each of the piles could not be made a correct component part of the arch. The principle relied on did not succeed, although of course it gave some support. The dam was let out to some Dutch contractors, who carried out the work on the Dutch principle, by sinking fascines and mattresses, and there was no doubt that it was a splendid success. That success had been purchased with a great deal of trouble. The pressure of the bank broke through the supporting medium, and there was no other resource but to completely fill up the site until a firm bottom was obtained, 50 or 60 feet below the surface. It took the contractors a year and a half to do the work; but they succeeded in the end, and the bank was as good as any that could be seen. There had been no sinking since the work had been completed.

Mr. SHOOLBRED wished to draw attention to two diagrams prepared at Mr. Hayter's suggestion; one (Fig. 5) in reference to

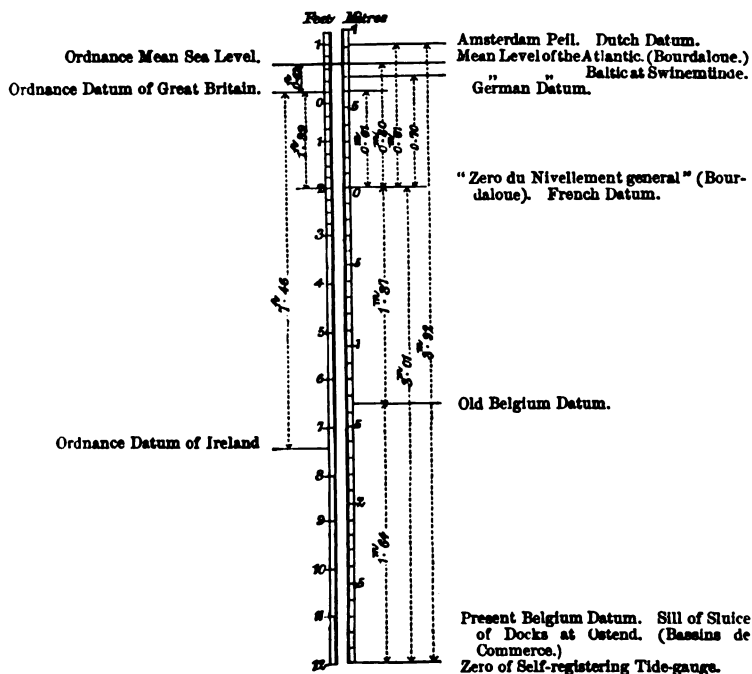
FIG. 5.



the tides at the North Sea entrance of the canal, and the other (Fig. 6) as to the Dutch official datum, and its position with regard to the datum levels of other countries. Those diagrams represented in part the labours of a Committee of the British Association, of which Sir William Thomson was the chairman. The tidal observations were taken for the committee by Mr. Hutton, at the entrance to the North Sea canal. Fig. 5 showed the equinoctial spring tide in March 1878, and two equinoctial

Mr. Shoolbred. neap tides; it would be seen how little difference in tidal range there was between them, 4 feet 4 inches being the average range of the neaps, and 6 feet 5 inches that of the springs. They formed a part of a number of simultaneous observations taken in 1878 along that coast, extending from the entrance to the Amsterdam canal to Havre, and also on the English side from Yarmouth to Portland. The reason for the construction of the other diagram was, that when the various observations were taken it became necessary to reduce those observations to one common datum, and then the difficulty arose of connecting the observations on the two sides of the channel. It was done on the assumption, that the mean sea level was uniform

FIG. 6.



on the two sides of the channel, and on that view the various datum official levels of the different countries had been collected, and were grouped upon the diagram. The information had been obtained as correctly as possible from official sources in each country. As the diagram showed clearly the position of the "Amsterdam Peil," so often referred to in the Paper, relatively to the official datum-plane of France, Germany, and of Belgium, as

also of Great Britain and of Ireland, probably it would be of Mr. Shoolbred. interest to the Institution.

Mr. GREGORY, C.M.G., Past-President, hoped the Author would Mr. Gregory. supplement his interesting Paper by some information as to the amount of dredging necessary for the purpose of keeping open the canal itself and the harbour at its sea end; also as to the effect of the tidal current and the sea action upon the influx of sand from the sea, and generally as to any circumstances affecting the maintenance of the channel, or of the harbour space within the breakwater. It would also be interesting to know what effect the formation of the dam had produced in the depth of water in the lake Y.

Sir JOHN COODE desired to ask a few questions, not at all in a Sir John Coode. captious spirit, but in order to obtain a little more information than was contained in the Paper itself on two or three points. He should like to know the reason why the locks in the Y dam were placed so far towards the northern side. Perhaps it was the nature of the foundation; he should be glad to know whether that was the case or not. The Author had mentioned that the fascine work of the apron was covered with a sort of pitching; he should like to know whether there was anything between the pitching and the fascine. With regard to the peculiarity of the piles recoiling to the extent of 18 inches after the blow unless the monkey was allowed to rest on their heads, could the Author give an idea of the weight of the monkey? He asked the question because a great deal of trouble was often encountered in pile-driving, simply for want of a sufficiently heavy monkey. He observed that the jetties or moles at the mouth of the North Sea reach of the canal were somewhat canted with regard to the direction of the entrance between the breakwaters. No doubt there was a reason for that, and perhaps the Author would explain it. Some difficulties had been mentioned that had been encountered in the maintenance of the staging by reason of the scooping action of the water around the feet of the piles. In sand of the treacherous character which had to be dealt with in this case, he could very well perceive that difficulties of that kind would be met with, but he fancied that a little rubble judiciously placed round the piles would have overcome that difficulty. The Author had mentioned that the latter part of the gales was almost invariably more destructive than the former part, but he did not state the reason. Sir John Coode had often observed it himself, and he believed the reason was that during the height of the gale when the wind was blowing very strongly, the crest of the wave was much broken up, and the water was, so to speak, highly aerated, but when the wind sub-

Sir John Coode. sided, the full force of the green water came in and broke upon the work, so that the shock towards the latter part of the gale was more destructive than at the former part. With regard to the bond in the breakwater, it appeared to him to be unduly small. He supposed that the vertical lines on the diagram represented the bond; if so, it was very small, and it almost looked as if the cramps had been put in to remedy that difficulty. Mr. Gregory had asked a somewhat pertinent question with regard to the maintenance of the depth of water in the North Sea harbour. He hoped that the Author would not overlook that question, and that he would state whether there was or was not any difficulty in maintaining the proper depth of water, or whether there was any tendency to silt in the channel, and if so, whether it existed to any extent. He hoped it would be clearly understood that he had asked the questions solely with a view of obtaining further particulars, because he thought that next to contributing information, it was the duty of every member of the Institution to endeavour to draw from the discussion as much interesting and useful information as the circumstances of the case admitted.

Mr. Fogerty. Mr. J. FOGERTY had been for a number of years professionally connected with Holland, and had taken considerable interest in Sir John Hawkshaw's work; and being in that country very recently, with a view of adding as far as possible to the facts so carefully collated by the Author, he had spent three days in examining all the works represented in the diagrams. He had also seen Amsterdam before any important part of the works had been constructed, and frequently during their construction, especially since the tidal water had been excluded from the harbour by the dam across Lake Y. Such works as canals in general were very little open to criticism; but this was not exactly a work of that class. It involved the introduction of what the Author had termed a "novel expedient," in the placing of a dam across Lake Y; and probably there was no harbour placed under similar conditions to those of the harbour at Ymuiden in the North Sea. It was not to be wondered at that the people of Amsterdam hesitated for a considerable time before adopting any plan which would exclude the tidal waters from their harbour. Amsterdam almost lay outside the track of trade, and had therefore great difficulty in maintaining its commerce. The efforts they had made in reference to the North Holland canal, opened in 1825, were very serious and expensive, and it was not a matter of surprise that they hesitated before adopting the present plan of connecting themselves with the North Sea by the harbour at Ymuiden. It was quite evident that if they had had means and knowledge enough at the period

to attempt the later work, they would not have attempted the earlier one, because the Helder was a port entirely out of the ordinary run of vessels trading to the country. In examining the dam across the Lake Y, it could readily be seen why it was that the locks were placed in the position they now occupied; because the old and deepened channels were originally near the centre of the dam, at the point at which it was evident all the great subsidences had taken place. In looking at the locks themselves, there was nothing to which any serious objection could be raised, except that he thought it was desirable to ask why it was, that considering the sea gates must be maintained and carefully watched, for the sake of the safety of the vast hollow country lying beyond, that in the piers supporting those gates no provision had been made for the introduction of caissons in the event of their requiring to be repaired. At present there appeared to be no means of damming across the locks, in case of repairs being required to the external gates. No doubt it was easy to take out and repair any of the interior ones; but with regard to the sea entrance gates, it occurred to him as strange that there was no recess in the piers as usually constructed, like those at Millwall docks, for floating in a caisson for the purpose of removing or repairing the gates. In the detail diagram of the heel post to the iron gates there was shown a large piece of timber, which it was said, "took the thrust of the gates when closed;" but on looking for that in the gates themselves at the Orange locks, it appeared that the hollow quoin was not made precisely as shown, but for a considerable distance the timber did not touch the masonry at all. There had been a recess cut out behind it, and it occurred to him that that was probably introduced for the purpose of getting rid of anything which might impinge between the timber and the masonry. At the North Sea gates that recess was intermittent; one of the bonds or starts of the masonry of the hollow quoin touched the timber, and then there was a recess at the next beneath and so on in alternate courses. He presumed that was introduced for the same purpose; but as far as one could judge, looking down the angles of the gates in the Orange locks, the timber did not really touch the quoin, unless it did below water. The gates themselves had nothing peculiar about them; they were just such iron gates as were usually constructed. The crab winches which hauled them together appeared to him to be extremely light for works otherwise magnificent in construction. There was not shown in the general plan something which appeared to have been introduced at a later period in a kind of curved breakwater thrown

Mr. Fogerty. round the side gates in the Orange locks. He presumed that that was introduced for the purpose of preventing vessels being carried through the side sluice or lock at the end, which was used for reducing the water in the Lake Y when the rainfall of the country exceeded the power of the pumps. Probably the engineers, if they had to do the work again, would provide larger pumping power than that which existed at the present time, because the very intelligent engineer in charge of the works had mentioned that, during great rainfall, those splendid centrifugal pumps, capable as they were of throwing 2,000 cubic metres of water per minute, were frequently unable to bring to the required level Lake Y and the canal appended to it, which it was most important should be kept at a certain fixed level below the Amsterdam Peil: consequently it was necessary to discharge a considerable amount of water through the locks themselves, and it was evident that in an important structure of that kind on pile foundations it would not be desirable, in a year of great storm overflow and excessive rainfall, to make a very large use of the discharging power of those locks, or of the side sluices attached to them. Since Sir John Hawkshaw's works were completed the Dutch engineers of the municipality of Amsterdam had erected about the point marked Paardenhoek, a second large system of pumping machines, but not of the same class or efficiency as those constructed by Messrs. Easton and Amos. The most important part of the subject, as it appeared to him, was, what would be the effect of totally closing out the tidal water from Lake Y, and placing Amsterdam, which previously had some means of discharging its sewage from the canals by the ebb and flow of the tide, in a tide-locked harbour? Probably Sir John Hawkshaw had taken into consideration how he would ultimately deal with the sewage of Amsterdam, but a number of works appeared to be going on there without any particular general plan, and the result was that, at the present moment, Amsterdam, or that central portion which was indicated on the map (which did not represent one half of the city) was simply one huge cesspool. It was impossible to conceive how, in any civilised country, such a state of things could be permitted to exist. The whole of the sewage—all the flotsam and jetsam accumulating from a vast population; all the dust, detritus and rubbish of every kind—was shot into the canals, and there seemed to be no effective means of flushing them. Amsterdam was built like a series of concentric rings, with stagnant canals in every street, so that the whole town was cut up into a number of islands, of which there were over three hundred, with a population of three hundred thousand

persons. No doubt commerce was to the Dutchmen of far more Mr. Fogerty. importance than any other consideration, and the desire to preserve the trade which Rotterdam, Flushing, and Antwerp would ultimately take from the people of Amsterdam, and were taking from them, induced them to construct the larger and more important work before they took the other into consideration. At the same time, he had no doubt that an English engineer did not execute that singular work of converting a harbour which had a difference of tidal level sometimes amounting to 7 feet during special winds, and so gave some means of clearing out the canals, without seriously considering the subject; and it would be interesting to learn by what means Amsterdam was to be ultimately relieved from the enormous mass of floating sewage which at present encumbered it. It was stated that fresh water could enter from the river Amstel to circulate through the city, but he had never seen anything of the kind. It was also stated, though no one seemed to be thoroughly well informed upon the subject, that sea-water could be admitted; but there was an objection to that on account of its precipitating the sewage. He believed that the remedy which had been proposed was, that the pumps or scoop-wheels erected at Paardenhoek were to keep down the level of the general canals in Amsterdam, and that the water from Lake Y was to be admitted, so as to force out the sewage and discharge it ultimately to the sea through the dam near Paardenhoek. Of course a better remedy than that would be to introduce some proper system of drainage into the city; but that was one of the most difficult problems that any engineer had yet attempted. In a portion of the town the system known as the Lieurner system had been adopted, but opinions were extremely divided about it. He did not think it would answer, but that ultimately it would be found necessary to lay cast-iron drain pipes of large dimensions in the beds of the canals so as to avoid siphons, and also that several of the worst canals such as the "Rokin" might be filled up with advantage. This would necessarily involve the construction of a low-level drain to the sea beyond the dam, and the use of considerable pumping power. In looking at the North Sea harbour and hearing the opinions of a number of Dutch engineers—not those particularly connected with North Holland, but those in the south, where there was no doubt some jealousy and a feeling of doubt as to the success of those works—one could not help forming an opinion that the existence of the harbour without a very great amount of dredging must necessarily be endangered in time. Even already there was the appearance of a moving forward of the foreshore. The sand, as far as he could judge on the

Mr. Fogerty. spot, had already formed a deposit much greater than was indicated in Plate 1. The whole of the sand of the coast had always taken a northward course; it passed the mouths of the Scheldt, and probably arose from the sea-worn rocks on the coast of Normandy, and with the south-west current it proceeded northwards, and would impinge first upon the southern pier, which he thought would act as a groyne. He believed also that sand would form rapidly behind the northern breakwater, and that it would be considerably added to by the wearing down of the large dunes adjacent. One could see the latter process going forward by a continual drift of sand blowing with the wind off the land, and it was an interesting question what time it would take for the overlapping of the harbour by the accumulation of sand behind the breakwaters. When that did arise it appeared to him that the natural result would be that the sand would be turned in and deposited in the harbour, or would form a bar at the mouth. It might be fifty or a hundred years hence, but that it would ultimately occur was a pretty general opinion amongst those best acquainted with the coast. The two moles shown at the entrance were, he presumed, supplemental works that were projected after the original design. They were shallow moles, their level being, he believed, about $1\frac{1}{2}$ mètre above the level of the canal. They were simply guide moles, and at present the sand was accumulating behind them so as to be almost level with them. Dredging was being continually carried on, and it would be useful to know what would be the cost of maintaining the harbour as an effectual entrance to Amsterdam. As to the construction itself, no fault could be found with it. It had been well done, and it was apparently as substantial a work as could possibly be erected, deserving all the praise that could be given to it; but on that coast there were very exceptional conditions, and there was probably no harbour in the world situated under such trying circumstances with respect to the amount of sand or its silting up as that harbour in the North Sea, and the result of this novel experiment would always be a matter of great interest to the profession.

Mr. Redman. Mr. J. B. REDMAN observed that the Paper had brought out one remarkable fact—for all the early harbour works along our south-eastern coasts, and all our early drainage and fen works were engineered by Dutchmen, who had left their impress to the present day, as in the case of King's Lynn, which still preserved its Flemish aspect. That, however, was during the Tudor and Stuart dynasties, but in the Victorian age the Hollanders came to Great Britain for Englishmen to engineer the greatest Dutch work of modern times.

Amsterdam, a great centre of commerce, handling about one-tenth Mr. Redman. of the tonnage of the port of London, was situate on a tideless sea, on a morass founded upon piles like St. Petersburg, and hemmed in from the ocean by remarkable sand dunes, many of which were of great antiquity, and were undoubtedly due entirely to wind action. The same thing might be seen on our own coast. To the eastward of Bournemouth was a line of sand dunes on the summit of a cliff of great height. At Eccles, on the north side of Yarmouth, the church was standing on the seaward side of the sand dunes, showing what their movement had been. The condition of the outfall of the canal described in the Paper was remarkable, inasmuch as it was situate near the parallel of the North Sea tidal node, the central point of the North Sea, where Captain Hewitt determined that the oscillation of a spring tide was only 12 inches. The North Sea tidal wave along the English coast was to the south, and along the Dutch coast from the south to the north there was in fact a rotary motion of the tide. The oscillation of the tide was but 5 feet at the entrance of the Amsterdam canal; this in stormy weather was however sometimes nearly doubled, and the tidal oscillation at Amsterdam might be said to be nil. It would be very interesting to know what were the arguments in favour of the particular treatment of the canal as compared with an open tidal cut to connect the Zuider Zee with the North Sea. The datum A.P. was the mean tide level; the oscillation of the tides in the North Sea at the outlet was but 5 feet; assuming that the level of the Zuider Zee was the same as the mean tide level in the North Sea, the fall of water was 30 inches; the fall to the eastward from the ocean would be 30 inches; the fall to the westward would be 30 inches; that would give a gradient of something like 2 inches per mile, which was about equivalent to the fall of the water in the Thames. With north-east gales the level of the Zuider Zee was sometimes abnormally raised 5 feet; under those conditions at low water the gradients of the ebbing water through the cut would be correspondingly increased. No doubt the Author would state that there were many practical objections to such a course, the lateral banks would have to be raised higher and also the drainage, but the question arose whether an open cut would have answered the same purpose. With reference to the circular dam the Author had referred to the great leakage induced by through bolts. Those who were acquainted with the proceedings of the Institution would remember that the late Mr. Rendel originally constructed his great dam at Grimsby with three rows of sheet piles and two puddle trenches, and connected the outer and inner rows of gauge piles

Mr. Redman. alternately with the central row of sheet piles, so that there was never a complete through bolt through the dam. He also made use of buttresses or counterforts of sheet-piles, which had likewise been used in the work described in the Paper. As to the rising of the gauge-piles, he might state from his own experience that in enlarging a dock in the Thames to take in three ships where only one ship could be taken before, the proprietor had often told him, that in the original construction referring to the nest of piles under the bridge, the platform and the gate recesses, frequently when those piles were driven down home, as it was thought, at night, that many of them would be found 12 inches higher in the morning. Great changes had been going on at Dover, but he did not think that the engineers of the work now in question need fear any great hindrance to their commerce. The particular form of entrance appeared to be admirable. It was so planned that in the event of a ship missing the entrance, she had the opportunity of wearing off, which was a great advantage. He thought the members were highly indebted to the Author for his description of a most important work forming the sea outlet to a very great centre of commerce.

Sir John Coode. Sir JOHN COODE said his remarks had had reference to the two moles at the end of the canal reach, and not to the entrance.

Sir John Hawkshaw. Sir JOHN HAWKSHAW, Past-President, remarked that as he had been professionally engaged upon the canal from its commencement to its completion, he might be expected to say a few words upon it. The Paper itself, and the drawings accompanying it, gave so many details as to leave little to be added, but there were one or two facts which it would be useful to state. The results of the canal to the trade of Amsterdam had been very important. Before the canal was opened the trade had varied little for many years. It was rather decreasing, if anything, and it amounted to about 2,000 ships and 800,000 tons annually. The canal was opened in November 1876, and in 1877 there passed along it 3,376 ships, amounting to 1,031,303 tons; in 1878, 3,242 ships, amounting to 1,136,527 tons; in 1879, 4,013 ships, amounting to 1,368,895 tons; and in the first three months of 1880, 654 ships, amounting to 273,289 tons; the corresponding period of 1879 showing 426 ships, amounting to 185,431 tons. It was well known that the last two years had been years in which no very rapid increase to trade could be expected. The peculiarities of the canal had been explained in the Paper. There was the necessity of shutting out the Zuider Zee from Amsterdam, and making locks in that dam to enable the shipping to get to and from Amsterdam; and shutting

out the sea by locks at the sea end of the canal arose from this circumstance, that the canal had to be made through shallow lakes which previously received the drainage of Rhine land. The drainage from a large area flowed or was pumped into them, and inasmuch as the lakes had been reclaimed and replaced by land, it was necessary so to construct the canal as to make it a receptacle for the drainage water; on that account it was a stipulation with the Government that it should be maintained at a low level, namely, $\frac{1}{2}$ meter under A.P.—A.P. meaning about the mean tide level. This would probably be a sufficient answer to a question by Mr. Redman, why the canal was not made open from sea to sea. Of course, if the sea flowed through the canal, the canal would have risen and fallen with the tides, and inasmuch as the time of high water in the Zuider Zee differed from that in the North Sea, there would have been a current to and fro between the two seas. That question had been considered, as well as a number of others, and the proposal referred to had been dismissed as impracticable. One or two questions had been asked which he might as well answer, and thus save the Author some trouble. In reference to the question of Sir John Coode as to the bond of the breakwater, the first portion, until it came near the wave-breaker, was made of blocks alternately 7 feet and 10 feet long, their breadth and depth being 4 feet 6 inches; but beyond that point it was thought better to make the facing blocks heavier, and from thence to the end of the breakwater, they were all made 10 feet 6 inches long. There was even then some bond, because the breakwater having a slope of 1 in 7 the blocks tailed over to a certain extent. The cramps were put in, not merely with regard to the bond, but because when a course of blocks was laid, and they became exposed to breaking waves, there was great difficulty in keeping the course in its place, and the blocks were cramped to hold them there, until a succeeding course of blocks was placed upon them. Near the top both blocks and cramps were abandoned, and the upper part was made of one mass of concrete. The position of the locks in the dam, referred to by Sir John Coode, was determined by himself. It was originally proposed to put the locks nearer the north side, because it was thought that it would be easier to construct them in that position; but it appeared to him that it would be difficult to keep a sufficiently deep water channel through the locks if they were placed so near the shore, and he consequently advised that they should be placed where they now were, and there had been no difficulty in maintaining a channel into and out of them. The angle of the

Sir John
Hawkshaw.

Sir John
Hawkshaw.

canal in entering the harbour was fixed by the concession, and there were reasons for it. It led from the Wijker Meer, and went in that direction to the sea; but in designing the harbour it was thought better to put it at right angles to the coast, which led to the apparent divergence of the centre line of the canal from that of the harbour. No inconvenience had arisen from that. It could not well have been avoided unless the position of the harbour had been altered, which he did not think desirable. With reference to the objections on the subject of sewage, he did not think it necessary to allude to them further than to say that the matter had not been lost sight of. Some day Amsterdam would have to remove the sewerage further from the town. At present the whole of the sewage of Amsterdam entered the canals which passed along the centre of the streets. The sediment was annually dredged out, but that was not a very desirable state of things; it was not, however, as objectionable as might be supposed, for Amsterdam happened to be a very healthy city. At the same time some day it might be worth while to make a low-level drain from Amsterdam to carry the sewage far beyond the embankment, and to raise it by pumping into the Zuider Zee. It had been stated that the municipality of Amsterdam had made a sluice at the Paardenhoek side, at the end of the dam. That arose in this way. When the dam was completed, and the locks were constructed, the Zuider Zee, which used to flow up to Amsterdam, was shut out, and the only water that came in from it was that which had passed through the locks. Then the conclusion arrived at by the municipality was that the water was not sufficiently "refreshed," and a passage was made at Paardenhoek, with a sluice through which water was admitted into Lake Y up to Amsterdam. He mentioned that mainly because it bore on another question asked by Mr. Gregory as to whether the shutting out of the Zuider Zee from Amsterdam would not lead to silting in the deep water opposite. He did not know that he was in a condition to answer the question at present, but there was no doubt that the construction of that sluice on the shallow shore of the Zuider Zee did in the first instance bring a considerable quantity of mud into the waters of Amsterdam. The water had to flow over a shallow shore, which was wholly of mud, and it necessarily carried a considerable quantity of mud with it. It was not possible to say whether in the course of time the effect upon the deep water of Amsterdam in the way of silting might not amount to something; possibly it would, but he did not think it would amount to anything so important as to affect the trade of the town, and

that could not be easily dealt with in the usual way by dredging. Another most important question connected with the undertaking had been asked by Mr. Gregory, whether there would not be silting in the harbour, and to what extent it would take place? There were at present disturbing elements in the consideration of that question, which rendered it impossible to give any definite reply to it. In the first place the canal had been newly formed. The berms, which were very wide through the lakes, and which were designed for the purpose of protecting the banks, though partially overgrown in many places, were not yet completely covered. When they became covered, as they would be, the denudation of the embankments and the shallow portions of the berms would be stopped. The reeds, when grown, formed a perfect protection against the wash of steamers, but they required time to grow. Then there was another disturbing element. In anticipation of the trade which the canal would bring, large works had been carried on in Amsterdam in the extension of the quays, the construction of large railway stations, and in increasing the area of the land upon which buildings were to be erected, which was done by the deposit of sand. Land could only be made in Amsterdam by taking it from the shallow surrounding seas. First sand was thrown into the shallow portions of the water, so as to convert the site into dry land. The whole of this sand was being fetched from the sides of the canal between Velsen and the locks, and the canal company had acceded to that, because the parties who fetched the sand and conveyed it to Amsterdam for the purpose of the works bound themselves greatly to increase the width of the canal between the North Sea locks and Velsen, which would be an advantage to the company; but in the meantime they dug away the slopes which had been left completely soiled above the water-level, and protected below, and those operations were going on when he was in Holland in August 1879. A considerable quantity of sand in these operations was dropped into the canal and carried out into the harbour, because at low water there was a current outward varying from 1 mile to $1\frac{1}{2}$ mile per hour. Until, therefore, the banks were properly consolidated and the slopes protected, it was impossible to say how much of the deposit in the harbour arose from that cause, or how much arose from natural causes. It had, however, always been assumed that there would be a considerable amount of dredging necessary to maintain the harbour and its approaches of the depths at which they were constructed. The principal portion of the deposit would come from the sea; but in the meantime, from the causes he had stated, some portion

Sir John
Hawshaw.

Sir John
Hawkshaw.

came from the canal. He believed that when the works to which he had referred had ceased, and the canal works were consolidated, there would not be a great amount of matter from the canal. There would always be a considerable amount from the sea, because the whole of the sand along the coast was blown sand, so remarkably fine that it was stirred up by every gale, and it was certain that a portion of it would rest in the harbour. A certain amount of dredging, therefore, would always be required.

Mr. Langley.

Mr. A. A. LANGLEY felt great interest in the subject under discussion, especially in regard to the use of sand pumps, which he had employed at Lowestoft. In pumping sand the best proportion of water to sand, according to his experience, was 5 to 1. He should be glad to know whether the sand was pumped pure, or whether it contained gravel or stones. In the dredger used at Lowestoft large stones and iron bucket pins were sucked up, in many cases over 3 lbs. weight. The dredger was 60 feet long and 20 feet broad; the suction pipe was 12 inches in diameter, 25 feet long and was composed of india-rubber, with coiled iron inside to preserve its shape. It terminated in a copper tube with a grating at the bottom, and a derrick supported the end of the flexible tube. A man stood at the end of the dredger, and lifted, or lowered it as required. If the material delivered into the hopper barge was dark he knew the dredger was lowered too much, and he raised it; if the material was light coloured he lowered the dredger, because there was too great a proportion of water. The pump was at the bottom of the dredger and forced the sand vertically into the open trough, the fan being 2 feet in diameter, and making about three hundred and fifty revolutions per minute. The fan had four blades, one of which broke, when it worked better; with two blades it worked better still. It had raised 400 tons of sand, gravel, and stones per hour, the average being 200 tons with a 10-HP. engine, and working in depths of water varying from 7 to 25 feet. Sometimes the sand was loose, and could be easily picked up, but at other times the stones interfered with the work, and the nozzle had to be carefully regulated. The total cost of this dredger complete was £2,000. Bucket dredgers were used for the inside of the harbour, and the basin dredger (a French invention) at the entrance where there was sand and gravel; it did not succeed well in silt, because the silt ran over the side of the barges without settling. Several plans had been tried to stop this, such as putting boards across the barge to prevent the water from rushing so rapidly over the sides, but so large a portion was held in suspension that it was not worth while using the dredger with mud.

Nor was it good for picking up solid clay ; it did the best work Mr. Langley. with sand and gravel, for which it was superior to the bucket dredger. Another great advantage was its capability of working in disturbed water where the frame of the bucket dredger would be injured. With the sand pumps used at the Amsterdam works he presumed there was not much wear, because the sand was pure, but where there were stones they choked the pumps, and the fan ; in fact they so blocked the pumps that the machine was at first almost a failure. An ingenious contrivance had been devised by the manager for the contractors, who made the fan small, and put india-rubber plates on it, leaving a large clearance. Since then there had been no wear to speak of, although previously the cast iron, malleable iron, and steel had all become worn. The cost of dredging was about 2d. per ton, including taking the material to sea, a distance of 2 miles. A total of about 200,000 tons was dredged every year at Lowestoft. The harbour was built out into the sea, and formed a groyne. The sand had gradually collected at the back until it had got to the mouth of the harbour about 1,000 feet from the original shore line. He had been instructed to take steps to prevent the sand working round the pier heads, and he proceeded to extend the jetty in an oblique line from the North Pier. This work had been attended with difficulty owing to the roughness of the sea. In the first place piles were driven 10 feet apart, then sheet piling, and counterforts which were afterwards filled up with heavy stones, chalk, and clay. The work which was now nearly completed had proved most effective.

Mr. ALFRED GILES was surprised to find that the dredging had Mr. Giles. been done at the small cost of 1½d. a ton. Of course, it was not to be expected that work of that kind could be carried out without some casualties, but looking at it as a whole, the work had been most successful. Some objection had been made to the angle at which the canal entered the North Sea, and to the position of the breakwaters, but he thought the angle entering the shore was of little consequence, when it was considered that the distance from the entrance between the horns of the breakwater was nearly a mile. He wished to ask a question as to the effect of those horns on the shore. The old notion was that they should act as groynes, and that there would be a deposit on the outside of each of those groynes ; but he had been informed that, instead of a deposit, there was a scour on both groynes. No doubt, with a strong tide in the North Sea, there must be some difficulty in vessels shooting the piers, unless they had some little way upon them. It appeared from the Paper that it was considered

Mr. Giles.

necessary for a vessel to have a way of 6 knots an hour to enable her to get in safely, and he thought that was likely. As to the cofferdam, he could not help thinking, looking at the section of the dam, and the load it had to carry, that it was not quite equal to its work, as indeed was proved by the accidents that had happened. He did not attach the same importance to the bank of sand inside as he should do to having some additional piles with braces, to keep the top of the dam in place. He would rather criticise the shape of the dam. The difficulty of fitting piles and walings to a circle was notorious; whereas, if the dam had been made as a box dam, with straight sides, having the corners cut off, he doubted whether the expense of the greater length would have exceeded that of the round dam; and he thought there was very little strength gained by the arched form, when it was considered that the radius of the circle was 262 feet, and the thickness of the arch (*viz.*, the piles) only about 13 inches.

Mr. Lavalley.

Mr. LAVALLEY said he had had but a short time to study the Paper, and he could only say that he considered the work a remarkable one, and that the means employed in making the canal were the cheapest and the best that could be adopted. The members might perhaps be interested by some account of the method he had employed in delivering the dredgers on the Suez canal, and bringing up the soil. He was aware, when he first ordered the plant, that the soil in the lakes was very variable, not only according to the different parts, but also according to the different lengths. The surface of the soil was loose mud, which lay in some places on sand (nearly quicksand), but more generally on clay more or less hard. The short time in which he had to do the work obliged him to have plant which could be adapted to the different descriptions of soil. Of course, pumping directly from the bottom, or pumping through pipes, was the cheapest way of getting rid of the dredgings; but he was afraid at starting that he could not pump out the very stiff clay met with in very great quantities along the canal. He thought that long shoots would be available for all sorts of soil, and his expectations were not defeated. In dealing with mud, the shoots, 230 feet long, carried away the soil with hardly any inclination at all. Sand flowed away, with a sufficient quantity of water, at an inclination of about 1 in 20; but when the sand was mixed with shells, they formed a coating, and protected the sand from the action of the stream, and even with an inclination of 1 in 10, it could not be got rid of. He then adopted a pair of endless chains working down the long shoot, 230 feet. In dealing with stiff clay, the man in charge

took care that the buckets were not choked, but whatever care Mr. Lavalley. was taken the clay was hard and compressed enough to fall out in lumps the exact shape of the bucket, and the shape was hardly altered by the clay falling into the shoot. To get rid of that the endless chain was quite sufficient. To facilitate the working of the chain when the shoot was almost horizontal, a very great quantity of water was pumped into the shoot. The men at the dredgers soon got clever enough to almost entirely fill up every bucket with clay, so that the quantity of water falling on the shoot was insufficient to help the chain in pushing down the clay; they had, therefore, to pump a certain quantity of water into the shoot, which had the advantage of floating the clay, and decreasing by nearly one half the weight of the large lumps on the bottom. The dredgers could turn out about 2,000 cubic yards of thick clay in fifteen hours. When the clay was not hard, they turned out 150,000 cubic yards in a month, with one dredger, for several consecutive months. He was now using pumps before the harbour of Dunkirk, pumping muddy sand from the bottom of the sea into barges. In another place he was digging out from a harbour coarse and heavy sand, and pumping it with great facility into long floating pipes (as used in making the Amsterdam canal) which did the work efficiently. The cost was about $1\frac{1}{2}d.$ per ton.

Mr. W. PARKES said Sir John Hawkshaw had answered the Mr. Parkes. question of Mr. Gregory and Sir J. Coode, with regard to the motion of the sand, so far as it affected the probability of the silting up of the harbour; but the Author might perhaps be able to give a little more information as to the actual changes that had taken place in the sand during the progress of the works as the piers were being projected into the sea. The Admiralty chart of the harbour, published two years ago, showed considerable irregularities in the ground, which he presumed must have been caused by the works, and although there was nothing in them that was not well within the control of the dredger, it would be interesting to know what the original state of things was, and something of the changes that had taken place. He thought that the details given by the Author and Mr. Lavalley, and other facts which were coming to light every day as to the very low cost of dredging, would tend to quiet the public mind on the subject of harbours silting up. If they did silt up it only involved a little annual expense in dredging. It was curious to observe the very different idea now prevailing about dredging, from that which prevailed twenty-five years ago. He believed that one case of dredging had lately been mentioned, which was more economical than either of the cases mentioned in the course

Mr. Parkes.

of this discussion ; he referred to the dredging of the canal in Lake Fucino in Italy.¹ He was engaged twenty-five years ago, under Mr. Gregory, in preparing plans for the drainage of that lake ; and Mr. Gregory was in communication with the late Mr. Brassey, with a view of his undertaking the contract. There was a large amount of dredging in the scheme, and Mr. Gregory and himself had estimated it at 6*d.* per cubic yard. Mr. Brassey accepted all the prices in their estimate with that exception, but thought the dredging ought to be put down at 1*s.* per cubic yard. Upon that the negotiations were broken off. The works were afterwards carried out under French engineers, who published an elaborate work upon the whole undertaking. The only point on which they gave any details as to the cost was the dredging, and they stated that the material of the canal was lifted from the bottom to a height of 30 feet above the water level, at a cost of 1½*d.* per cubic yard, not including any charge for the first cost of the plant, but simply for working expenses and maintenance of plant. He imagined that if the cost of the plant were spread over the quantity of dredging done, 1*d.* or 1½*d.* would cover it ; so that Mr. Brassey's shilling, and Mr. Gregory's and his own sixpence, was brought down to 2½*d.* or 3*d.* per cubic yard.

He wished to ask for some explanation with regard to the wave-breakers, to which no allusion had been made. When the section of the pier was brought forward four or five years ago, with respect to the breakwater at Kurrachee,² that wave-breaker did not appear, and he understood that it was an addition that had since been made. He should be glad to know what were the circumstances which led to that addition being made, especially whether there were any indications of scouring which threatened the safety of the structure, and led the engineers to apply that protection ; and also whether the blocks were themselves perfectly stable in the position in which they were placed. It was rather a costly addition, amounting to one-third of the cost of the pier itself, and it was one, therefore, on which a full explanation seemed desirable.

Mr. Harrison
Hayter.

Mr. HARRISON HAYTER in reply, said, that Sir John Hawkshaw had answered several of the questions, and he would not go over the ground again. Mr. Gregory had inquired as to the anticipated silting at the North Sea harbour, and as to the silting at the Zuider Zee, to which Sir John Hawkshaw had replied fully ; but

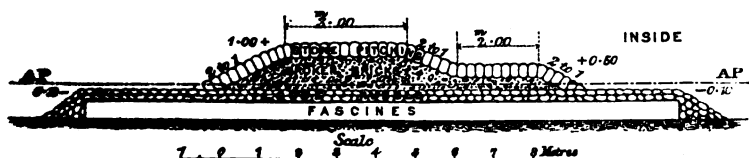
¹ Vide "The Drainage of Lake Fucino." By Alexander Brisse and Leon de Rotrou. Rome, 1876.

² Vide Minutes of Proceedings Inst. C.E., vol. xliii., Plate 2.

he also asked whether there was any silting in the canal itself. Mr. Harrison
It was satisfactory to know that practically there was none. As Hayter.
regarded silting at the Zuider Zee he believed it was not such
as would affect any interests, and the channel to the canal from
the Zuider Zee could be well maintained, inasmuch as whenever
practicable the water in the canal was lowered to the prescribed
level through the sluices in the Zuider Zee system of locks, in-
stead of by pumping, and this scoured and maintained a sufficient
channel.

In answer to Sir John Coode's question, why the locks were
placed so near to the northern side of the Lake Y, he might
state that their approximate position was fixed by the concession.
It was desirable that the locks should, for convenience, be near the
shore, and one reason why they were placed on the northern side
in preference to the southern side was because the ships and
craft going through them were destined, either for places on
the Zuider Zee, or to pass to the North Sea through the Texel
roads. This shipping would thus be clear of the vessels going
to Amsterdam. Sir John Coode had also asked whether there
was anything between the fascine work and the top pitching in
the chambers and aprons of the locks. This pitching was of
basalt, and it was laid on a layer of broken bricks, averaging
about 9 inches thick, interposed between the fascine work and
the top pitching. The weight of the monkey used in driving
the piles of the cofferdam at the Zuider Zee locks was 1 ton,
so that the difficulties encountered in connection with the recoil
of the piles did not arise from the fact that the monkey was
not heavy. The guide moles leading from the harbour to the
canal were constructed parallel to the centre line, and this being
slightly curved, the passage between the moles was well shel-
tered. The moles were 220 mètres apart from centre to centre, and
were constructed in places on a foundation of fascine work, upon

FIG. 7.



which loose rubble stone was laid, and upon this broken bricks
covered with stone pitching. Fig. 7 was a sketch of the central
part of the moles.

Mr. Harrison
Hayter.

Nearer the land the moles consisted of broken bricks pitched with stone, the general sectional outline, however, being as shown on the sketch. At the land ends the moles were connected with the slopes of the sand hills, which, just there, were for a short distance covered with clay 1 mètre thick pitched with stone. In this country instead of solid moles a guide structure of timber-work, carried up above high water, would probably have been adopted; but the channel between the solid moles was well buoyed off, and there were beacons at the sea end of each mole. The aggregate length of the two moles was 670 mètres, and their cost was nearly £23,000, or at the rate of rather more than £34 per lineal mètre. No rubble stone had been tried round the piles of the staging used at the outset to construct the piers, but afterwards abandoned as described in the Paper. Mr. Hayter simply stated it as a fact, that the latter part of the gales affecting the breakwater were more destructive than the former part. The gales begun in the south-west and generally ended in the north-west, the latter part of the gale being usually more destructive than the former. It might, to some extent, be owing to the circumstance that there was a greater exposure from the north-west, but beyond this he would not venture to give an opinion as to why the gales were more destructive towards the end than at the commencement. The occurrence was not an unusual one, as Sir John Coode had observed.

The question had been asked by Mr. Fogerty why grooves were omitted in the locks for the introduction of caissons or dams for repairing the gates. These would be expensive additions to the locks in question, involving heavy foundations and coursed ashlar work. They were common in locks in this country, but were seldom brought into use in practice. It was found very easy to take out a gate and renew it by another, and this had been done in the canal. The recess behind the gate of the locks at the hollow quoins was only in the top courses above the water line. Owing to the small tidal range the lock gates were always in a state of considerable buoyancy, and there were no rollers, so that they were easily manipulated. Hence the crabs for opening and closing them were of the light construction noticed by Mr. Fogerty. The curved timber-work at the Zuider Zee locks was constructed to guide the vessels.

The canal, besides being a navigation, was a large arterial drain receiving the water from extensive lands, and united with the canals and rivers of Amsterdam. Hence the level of the water had to be kept low, and this level was fixed at $\frac{1}{2}$ mètre below A.P. necessitating locks at each end. Moreover, as Sir John Hawkshaw

had observed, in reply to observations from Mr. Redman, the time of high water in the North Sea and Zuider Zee differed materially, so that there would have been a current through the canal if there had been no locks.

Mr. Harrison
Hayter.

With reference to Mr. Giles' remarks there was no doubt that the full advantage of the circular form of the cofferdam for constructing the Zuider Zee locks was not obtained, but this was owing to the dam becoming crippled; had the dam been made stronger at the outset greater advantage would have resulted from the circular form. Further, the outline of the Zuider Zee locks was such that they were better enclosed by a circular than by any other regular figure. Hence both for structural and economical reasons the circular form was most desirable. The best way to make the walings in a circular dam was by planks, which could be bent to the form of the dam, and be made to break joint. In this way, also, there was but little waste of timber.

There was no doubt some scour at the extremity of the south breakwater. The flood current impinged on the south breakwater, and then ran along the outer arm or cant to a short distance seaward, creating scour near the end of the south breakwater and depositing material at the end of the north breakwater, where still water was created by the deflection of the current seaward by the cant of the south breakwater. The ebb currents, acting in the opposite direction, lessened this deposit; but as the flood current was stronger than the ebb, there was an accumulation. This might get less and would not probably cause a great expenditure for periodical dredging if such were necessary, and the scour of the south breakwater had been prevented from creating undermining by the deposit of some concrete blocks. If the outer cant had been placed more in a direction parallel to the coast, the scour might have been somewhat less. On the other hand, the direction in which it was placed created still water for a short distance in front of the entrance, which facilitated the passage of ships between the heads of the piers. The addition of the wave-breaker was, as Mr. Parkes had observed, an afterthought. The blocks, after assuming a slope of about $1\frac{1}{2}$ to 1, remained stable. The state of the coast before the breakwater works were begun would be gathered by reference to Plate 1, Fig. 3, which showed that the contour lines at the extreme north and south on either side of the piers had been unaltered. If these contour lines were joined in a direction generally parallel to the coast, the original state of the ground would be obtained with sufficient accuracy.

Mr. Harrison
Hayter.

More than one speaker had alluded to the accumulation of sand outside piers and breakwaters of the kind described in the Paper. The general proposition might be stated thus: that if piers were constructed on a sandy coast where there were littoral currents there would be a recession of the contour lines, owing to the accumulation of sand; and if this were allowed to go on, the time might come when the piers or works would be left high and dry. While assenting generally to this theory, Mr. Hayter would remark that the process would, as a rule, be a slow one, and it might be several years before mischievous results would follow, provided no remedial measures were resorted to. But piers and breakwaters, like docks, railways, and other engineering works, required to be maintained, and by the expenditure of a small periodical sum any mischief from such accumulation might be hindered. At present the North Sea piers were an exception to this theory, inasmuch as instead of the contour lines receding seaward, they, especially at the seaward end of the piers, advanced landward. Possibly the reverse action might take place in course of time, and indeed the low-water line had slightly receded at the landward end of the piers; but should this go on there need be no apprehension that it would occasion any large outlay to remove the sand, as Mr. Parkes had justly remarked.

Although not mentioned in the discussion, yet, in some quarters, at different times, the performance of the pumps at the Zuider Zee locks had been questioned, and he should like to say a word thereon. Mr. T. E. Harrison, Past-President Inst. C.E., had alluded to these pumps in his Presidential Address,¹ they being the largest of the kind ever erected, and Mr. Hayter was responsible for the figures then given. These figures were derived from a diagram prepared by Messrs. Easton and Anderson as the result of experiments. The performance being doubted, the question was inquired into, the discharge having been tested by experiments made by Mr. Dirks and Mr. Waldorp. These experiments were at lifts varying from 1·84 foot to 5·02 feet, the lift given in the Paper being 7·20 feet, and the total lift given in the diagram being 9·75 feet, and there was no reason why the laws should not apply to these higher lifts. In one experiment only was the discharge less than that given by the diagram; and in some cases the results were very close. Thus an amount of 401 tons was observed against 395 tons recorded by the diagram, and again an amount of 333 tons was

¹ *Vide Minutes of Proceedings Inst. C.E., vol. xxxvii., p. 232.*

observed against 325 recorded, in both cases by one engine. Further, a Paper had been read before the Institution by Mr. Welsh in 1872, on the pumping machinery at Lade Bank on the river Witham drainage.¹ These pumps being similar to those at the Zuider Zee locks, excepting that the fan was 7 feet instead of 8 feet in diameter, Mr. Welsh found the results come very nearly to the quantity obtained from the diagram prepared by Messrs. Easton and Anderson. Under these circumstances Mr. Hayter was satisfied that the discharge he had given of the pumps at the Zuider Zee locks, viz., 670 cubic mètres or tons of water per minute by each pump, with a lift of 7·20 feet, was not overstated. The number of strokes to obtain the discharge would be 34 per minute, the length of the stroke being 2 feet 6 inches, and the pressure of steam in the boilers 50 lbs. per square inch.

As to the expenditure on the breakwater, the piers, without the wave-breakwater, cost £64 a lineal foot, and the wave-breaker £22 a lineal foot, or together £86 a lineal foot. This was the cost freed from financial surroundings, and with an allowance for reasonable profit. This portion of the work was, comparatively, proceeded with uninterruptedly, so that the price was not seriously enhanced by delays. It was difficult to compare the cost of one breakwater with another, the conditions being generally dissimilar; but considering the average depth of water, and the difficult nature of the foundations, this price could not be considered high. The greatest progress made with the piers was about 300 lineal mètres a year at each pier.

The cost of the land reclamations had been £26 an acre, after making deductions for financial arrangements. The selling price was about £70 an acre, so that a good profit had been realized; but it must not be forgotten that some time was spent in executing the works necessary for the reclamations. The price, moreover, was exceptionally low, owing to the circumstance that the main banks of the reclamations were also the banks of the main and branch canals, and these were included in the cost of the canal earthworks. Some persons connected with the canal had recently reclaimed some land at Legmeer, not far from Amsterdam. There the cost had been £33 an acre, and this was a better example to take as to the cost of reclamations under generally like conditions, as it was not surrounded by anything abnormal. Assuming it occupied about four years to complete such reclamations, and that

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. xxxiv., p. 178.

Mr. Harrison
Hayter.

the selling price was £50 an acre, this would give a sufficient profit to render it expedient to undertake the work. In the above cost of reclamations, both in the canal and at Legmeer, there was included a sum of £2 an acre for preparing the ground for seed, embracing levelling, soiling, and cutting small grips.

The dredging was in two divisions, that in the canal and that in the harbour. As regarded the canal dredging, he could give no further particulars beyond those contained in the Paper; that was that the cost by the dredgers fitted with the Woodford Pump delivery apparatus was 1½*d.* per ton of material dredged and deposited on the banks, which price included depreciation, interest, cost of plant, and repairs. It was simply the cost of the daily wages and fuel. As regarded the dredging in the harbour the only information he had given in the Paper was that it cost by the sand pumps less than 1*d.* per ton of material raised and deposited in the barges, excluding transport, depreciation, interest, cost of plant, and repairs. Now the dredging in the harbour was done in two ways, by ordinary bucket dredgers and by sand pumps. By the ordinary bucket dredger, hired from the River Tyne Commissioners, it cost 8·328*d.* per cubic yard, and by the sand pumps 7·234*d.* per cubic yard, including dredging, transport, interest, and depreciation, but excluding the prime cost of plant. It must be remarked that operations could not be carried on during stormy weather, as the material had to be conveyed two miles to sea. The number of working days in the year for this reason averaged only about one hundred and fifty. The cost of plant was 23*d.* by the bucket dredger, and 17·80*d.* by the sand pumps per cubic yard dredged per annum, so that both as regarded the cost of dredging and the cost of plant, the advantage was with the sand pumps designed and arranged by Mr. Hutton. The following Table (see next page), furnished by Mr. Hutton, gave further details of the cost of dredging in the harbour.

The material raised by the pumps was sand, with occasionally small stones. Some fine silt was met with, which was better dealt with by the bucket dredgers, inasmuch as it would not settle if pumped into the barges. The arrangement for adjusting the position of the sand pumps would be seen upon reference to Plate 3, Figs. 7, 8, 9. The suction pipe buried itself almost at once to the required depth of 3 or 4 feet from the top of the ground, and there was not any difficulty in this respect. These remarks were made in reply to Mr. Langley's observations.

COST OF DREDGING the HARBOUR by ORDINARY BUCKET DREDGER, and by SAND PUMPS. Mr. Harrison Hayter.

Prime Cost of Plant (approximate).

	Ordinary Bucket Dredger.	Sand Pumps.
	1 bucket dredger. 3 steam hoppers. Transport 2 miles.	12 sand pumps. 28 hopper barges. 5 steam tugs. Transport 2 miles.
	£.	£.
Dredger or sand pumps	25,000	60,000
Barges and tugs	15,000	26,000
Total	40,000	86,000
	Cubic yards.	Cubic yards.
Cubic yards dredged per annum	417,380	1,159,720
	Pence.	Pence.
Cost of plant per cubic yard dredged } per annum }	23·00	17·80

Working Expenses.

	Ordinary Bucket Dredger.			Sand Pumps.		
	Dredging.	Transport.	Total.	Dredging.	Transport.	Total.
	Pence per cubic yard.	Pence per cubic yard.	Pence per cubic yard.	Pence per cubic yard.	Pence per cubic yard.	Pence per cubic yard.
Wages.	1·792	1·439	3·231	1·117	1·494	2·611
Coal	0·804	0·803	1·607	0·526	0·531	1·057
Stores	0·269	0·269	0·538	0·058	0·036	0·094
Repairs	0·171	0·171	0·342	0·492	0·778	1·270
Sundries	0·155	0·155	0·310	0·211	0·211	0·422
	3·191	2·837	6·028	2·404	3·050	5·454
Interest and depreciation 10 per cent. on cost. }	1·437	0·863	2·300	1·242	0·538	1·780
Total	4·628	3·700	8·328	3·646	3·588	7·234

NOTE.—The bucket dredger used approximately the same quantity of coal as the three steam hoppers. The accounts for stores, repairs, and sundries, not having been kept separate, have been equally divided between the dredging and the transport.

The above does not include general superintendence, risk, insurance, amortization of plant or profit.

In conclusion, he would express his satisfaction at the complete success of the undertaking. Sir John Hawkshaw had given some

Mr. Harrison
Hayter.

figures as to the increased trade at Amsterdam since the canal was opened in November 1876, from which it appeared that the tonnage of the shipping to Amsterdam would be doubled before the end of the year 1880, whilst the number of ships had already more than doubled. It was always a matter of congratulation to be associated with a work that had resulted in success, and this effect upon the trade of Amsterdam, and that during a period marked by extreme commercial depression, demonstrated the great utility of the canal to Holland in general, and to Amsterdam in particular.

Correspondence.

Mr. Russel
Aitken.

MR. RUSSEL AITKEN had always considered it a mistake to expect that the upright walls of the North and South breakwater could be maintained on sand such as that which was known to exist at the entrance to the Amsterdam Sea canal. The thickness of the breakwaters was, he thought, ample to meet the force of any waves which they would have to encounter in a position such as this, where the sea in front of the harbour was so shallow, and where, of course, large waves could not reach the breakwaters. When at Dover breakwater, he had carefully noted the action of waves on an upright wall, starting at once from the bed of the sea; and he had observed that the force they exerted was small compared with what was exerted by them when they meet a wall built on the top of a sloping bank of stone, as at Alderney or Tynemouth. If the sand underneath the foundations of the Amsterdam Sea canal breakwaters could have been maintained in position, the breakwaters were amply strong enough. What caused the breaches in the works during progress was not, in his opinion, the insufficient thickness of the breakwaters, but the action of the back lash of the waves undermining the insufficient rubble base, and so the foundations of the breakwaters.

To show how little force the sea exerted on a vertical wall raised from the bottom of the sea, he would instance the case of the parapet of the breakwater at Dover, which, although it was 11 feet high, was but 4 feet 6 inches thick. In 1862 he proposed to strengthen this parapet where it faced the south-west by 3 feet more of masonry, but his views were not adopted, and the parapet remained only 4 feet 6 inches thick. Notwithstanding that this parapet was so high and so slight, it withstood the storms of fifteen years, and was only overthrown by a violent storm, accompanied by a high tide, which brought a greater weight of water against it than it could withstand.

Mr. IMRIE BELL could quite appreciate the obstacles which the Author stated had to be encountered in regard to financial arrangements, along with the limiting of the rate of expenditure from time to time; such difficulties being often harder to surmount than the engineering ones. He presumed they had in a great measure prevented the Author from going into minute details of expenditure. In the heads of total expenditure it would, however, have been more satisfactory had the Author given, 1st. The actual cost of dredging and excavation per cubic yard; 2nd. The cost of cofferdam per lineal yard; 3rd. The price per cubic yard of concrete blocks set in place; 4th. The cost per lineal yard of the dam across Lake Y. It would also be valuable to have a description of the plant used in the construction of the work. In describing the use of the overhanging cranes, called Titans, the Author stated that several designs were tried, and that the one employed on the South breakwater (of which he gives no description) answered throughout very well; but that the North breakwater, being more exposed, it was decided, after the works had been considerably advanced, and two Titans had been swept away, to employ a steam travelling crane, which was run out to its work by a locomotive engine, and brought back every evening for security in case of storms. He thought these Titans might have been constructed so as to traverse backwards and forwards by their own machinery. He now came to a paragraph of the Paper which required some explanation; it was stated: "When the piers were originally designed, the information supplied as to the rise of the tides was inaccurate, the tidal range being much greater than was then assumed. Partly in consequence of this, the design proved too near the margin of safety for a sea work, and when the breakwaters were considerably advanced seawards, the wave-breaker on the sea side was added." He should like to ask the Author to state the amount of difference between the inaccurate assumed level and the actual levels of the tidal range, also when it was discovered, and the reason for adopting such an expensive structure as the "wave-breaker." It was stated in a former part of the Paper that the rubble deposit was allowed to lie for twelve months before being built upon, which made it appear that ample time had been afforded for the purpose of ascertaining the true range of tide, and to allow of such modification in the design being made as might be necessary. It seemed strange that, in place of modifying the design to suit the necessities of the situation, an additional work of such magnitude, costing nearly a third of the whole cost of the main work of the breakwaters themselves, should be substituted.

Mr. Dyce Cay. Mr. W. DYCE CAY thought the North Sea piers enclosing Ymuiden harbour would have cost less if a section similar to that of the New South breakwater¹ at Aberdeen had been adopted. For that work the original design had been similar to that for these piers, but on commencing operations he had seen the economy and increase of strength to be gained by substituting liquid concrete building *en masse*, in place of concrete blockwork, in the whole work from about low-water level upwards, and he had devised a system of timber framework, lined and floored with jute cloth, by which this was easily accomplished. This plan made the part of the work, where the shock of the waves was most severe, so solid that a "wavebreaker" such as that described in the Paper was not required. Also, he considered that the apron, which would in that case have been necessary to protect the rubble foundation from the scour of the waves along the toe of the work, might have been advantageously constructed of concrete in bags, a description of work which was less liable to be disturbed by the waves than that formed by prismatic concrete blocks. With reference to the form of the harbour, he observed in the Paper that the littoral current of the flood-tide running from the south was caught by the north pier, and flowed along it into the harbour, and with greater force, he supposed, than would be due to the current caused by the rise of the tide in Ymuiden harbour. This, he thought, was to be regretted, as, being a sand-bearing current, it would deposit sand in the harbour, and form sand banks, and possibly a bar, an annoyance from which otherwise the entrance might have been nearly exempt. This interception of the littoral current might, however, have been unavoidable, owing to the heaviest seas coming to the harbour from the north-west.

Mr. Doherty. Mr. WILLIAM J. DOHERTY observed that the Paper would probably be consulted by many young engineers, as giving a clear and concise view of one of the gigantic undertakings of modern engineering. The "mattresses of fascines," used for the purpose of preventing sinkage in the dam, or embankments, might be judiciously copied by railway engineers in passing through estuaries, or over other doubtful foundations. In one instance which had come under his notice, if such had been adopted, much time, labour and cost would have been saved. In making the embankment through the Rosse's Bay, on the Derry and Coleraine railway, the sinkage there was estimated at about 80 feet. The cofferdam used for constructing the locks, situated in Lake Y, and its mode of

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. xxxix., p. 126.

construction, was highly interesting to every one engaged in Mr. Doherty. carrying out submarine works. It was easier to criticise a work after it had been executed, and when the weak points had been pointed out, than to originate a design of such magnitude and to carry it into execution. In theory nothing could be better designed than a circular dam of such dimensions; but in practice, he was of opinion that a dam having six straight sides, each of 300 feet, would have been an improvement, supported on the inside by two rows of piles driven 30 feet apart, and bound together by wales, into which struts calculated to receive the whole weight of the dam would be placed. By these means less trouble would have been caused in setting out correctly the line of the dam, the piles could have been more carefully driven, and the resistance throughout would have been uniform. The only danger to be dreaded in a dam of great magnitude, was impounding a quantity of water higher than the level of the tidal water outside at low water. If the pressure from without could always be kept as a constant quantity, which might largely be done by the adoption of the method explained by himself, of placing earthwork on the outside of the dam, reaching up to half-tide level, then sufficient struts and supporting piles inside would be all that was required to carry the whole superstructure in safety. A sufficient number of ordinary valves (such as were used for water mains) to enable the tidal waters to flow in and out until the pumping of the dam was commenced, was a great safeguard against the pressure of water inside ever being allowed to get higher than on the outside. Indeed, no dam should be constructed without having such a provision. Circular dams, except under special circumstances, should be avoided, for the further reason that the walings were more easily applied to a straight line than to a curved one. The sluices should always be placed about 2 feet above low-water level, so as never to allow the head of water inside to exceed 2 feet. Pump wells should, if possible, be always placed a good distance away from, and out of immediate contact with, the cofferdam, as no doubt the vibration of the pumping engines, as alluded to by the Author, and the continuous drawing of sand, should any be in the vicinity, created vacuities that continually increased unnoticed, until an abrupt "blow" occurred. On the whole he believed that as little weight as possible should be placed inside and adjacent to a cofferdam constructed of piles, and that an extensive toe of earth should be placed against the outside of the dam, sloping up at least to a level above low water. The Author had very properly alluded to

Mr. Doherty. the leakage occasioned by through bolts; and as the use of through bolts was merely for the purpose of holding the dam together and preventing the puddle from spreading it open, then the quantity of puddle being reduced to the lowest minimum, the tie bolts might be also reduced to a degree just sufficient to carry the weight of the puddle. One of the most successful cofferdams that he had dealt with was the one surrounding the central pier; and also the north abutment of the new swing bridge over the Liffey, which had just been completed, under the specification of Mr. B. B. Stoney, M. Inst. C.E. Here, although completely surrounded with a head of water of from 23 to 25 feet, at high water, the use of puddle and through bolts had been dispensed with. The dam consisted of a single row of 12-inch piles driven closely together in sets of three, dowelled to each other, and the joints caulked with oakum. As the excavations inside the dam reached the rock into which the toes of the piles were driven, the whole interior face of the piles was exposed, when the excavations were taken out, yet the driving, caulking, and strutting was so secure, that not a single "blow" occurred, although the foundations were taken down to 20 feet below low water. He thought that two rows of piles driven down to the same level, at distances apart of either 4 or 6 feet, tended to break up, cut, and crack the substratum through which they were driven, and frequently caused fissures to be more easily acted upon by water from outside finding its way through to the pump well, especially in ground so treacherous as that described by the Author, upon which the cofferdam of the Zuider Zee had been constructed.

Mr. Messent. Mr. PHILIP J. MESSENT stated, in reference to the Tyne dredger, that three steam hopper barges were hired with the dredger, and were included in the first cost of £40,000. These were let to the Amsterdam Canal Company in May 1877, at a rental of £154 per week, being £100 for the dredger and £18 for each of the barges, exclusive of the wages of the crew, insurance, fuel, and cost of maintenance and repairs. Although originally only hired for six months, the plant was retained for two years; half rent being paid during the winter months, when it was not in use. As the above arrangement was made and continued by the canal company after experience with the pump dredgers, it did not seem to justify the remark, that the cost of raising material with the bucket dredgers, or at all events with that from the Tyne, was more than with the sand pumps. Mr. Messent had been informed that during eight months in 1878 the work done gave an average of 679 cubic metres for each of the pump dredgers, of 699 cubic metres for each of the

local bucket dredgers, and of 1,994 cubic mètres for the Tyne Mr. Messent. dredger. He also understood that the pump dredgers were not fit for finishing work; they made a deep hole, but for completing the bottom and slopes it had been found necessary gradually to discontinue the use of the pump dredgers, and to increase the number of bucket dredgers.

Mr. G. H. PHIPPS observed, that in his remarks¹ upon Mr. Mr. Phipps. Blandy's Paper the Author had expressed his preference for wooden gates over iron ones, especially near the sea. In the present Paper it was stated² that iron was considered by the Dutch authorities to be more trustworthy than wood. The reason for the adoption of that material was, therefore, out of deference to the Dutch opinions. The hollow quoins referred to, so common in Holland, no doubt admitted of easier workmanship in preparing the flat surfaces instead of the circular ones usual in this country; but it appeared to involve the rather serious mechanical difficulty of making those surfaces come into contact with the sill and the other two surfaces at the same time. With reference to a proposition formerly made by him, to allow a certain play, or freedom of vertical motion, to the rollers of lock gates, to which the Author of the present Paper objected, that "such a contrivance would seldom be brought into operation, and the joints would not be kept oiled," Mr. Phipps thought the apparatus so simple and self-acting that it could not fail of coming into operation when required, and that the oiling would be easy.

Mr. VERNON-HARCOURT observed that he had visited the cofferdam Mr. Vernon-Harcourt. in Lake Y, in company with Mr. Watson, shortly after the mishap referred to in the Paper. It appeared to him that the cofferdam had been considerably shaken by the unexpected pressure from the inside, and he thought that the difficulty subsequently experienced in keeping the cofferdam watertight was partly due to this cause. He could not agree with Mr. Watson in thinking that the circular form was a mistake. The segmental cofferdam erected across the Blackwall entrance to the south dock of the West India Docks had stood remarkably well,³ and the circular form appeared specially suitable in Lake Y. Through bolts were a necessity in that form of cofferdam, but probably the leakage along them was increased by the settlement of the clay inside on the very soft bottom, in addition to the shrinkage which always occurred. A peculiarity in the locks was the employment of a paving of fascine and basalt, instead of an invert, between the gates; but this

¹ *Vide Minutes of Proceedings Inst. C.E., vol. lix., p. 75.*

² *Ibid., p. 13.*

³ *Ibid., vol. xxxiv., p. 164.*

Mr. Vernon-
Harcourt.

was rendered practicable in consequence of the small rise of tide, and by the enclosure of the space by sheet piling. The plan adopted for the hollow quoins, referred to by the Author, saved a great deal of expense in dressing them; but the danger of rubbish getting in between the keelpost and the hollow quoins, thereby tending to prevent the tight closing of the gates, was an objection. The dispensing with rollers for the gates was a great advantage; but the small rise of tide rendered this easier in Holland than in this country.

The winds appeared to veer round on the shore of the North Sea just as he had observed them do at Alderney,¹ the greatest force being attained from the north-west, the waves also increasing with the length of duration of the gale; and consequently the greatest damage occurring towards the close of a storm, and to works exposed to that quarter. The Author had attributed the necessity of protecting the outer portions of the piers partly to the tidal range having proved greater than had been assumed; it would be interesting to know what that rise was. He gathered, however, from an account of the works by M. Croizette Desnoyers² that the storms on that coast were more vehement than had been anticipated, as it was stated that the works were damaged considerably several times during construction, and that the blocks had to be made much larger and tied together, and the proportion of cement increased. It would be interesting if the Author could state whether these accidents occurred merely to the exposed end of the unfinished structure, or whether the finished portions were also injured; also where the injuries occurred, whether below low water where the blocks were not cemented together, or above that level. If the lower blocks were forced out, a mound of protecting blocks was evidently an indispensable necessity; whilst, had the force of the storms been known at the outset, injury above might have been prevented by wider piers and the continuous masses of concrete finally adopted. The position of the piers resembled somewhat those of Kingstown harbour, which, though situated in a sandy estuary, had not suffered from any progression of the foreshore; and at Kingstown the depth of the harbour at the entrance and inside had been easily maintained. He imagined that the strong tidal current across the ends of the North Sea piers would tend to produce a scour at that part; that the depth inside

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. xxxvii., p. 75.

² "Notice sur les Travaux Publics en Holland." By M. Croizette Desnoyers, p. 31.

the piers would be maintained without difficulty by dredging, and that the only danger to the maintenance of the harbour would be a progression of the foreshore. From the advance of the low-water mark at Calais, Dunkirk, and Ostend, in proportion to the extension of the jetties, it might be feared that the North Sea piers, jutting out into the sea on a sandy coast, would cause an accumulation of sand to form outside them; the sand being either brought along by the strong flood tide from the south, or blown in against the north pier by the north-westerly winds. As there appeared to be some divergence of opinion in this respect between Mr. Fogerty, who stated that the sand was accumulating rapidly on both sides, and Mr. Giles, who said he understood the shore was somewhat receding, he thought that a statement from the Author as to the alterations in the line of the shore and in the depths, as far out as the end of the piers, outside the harbour since the commencement of the piers would be valuable.

Mr. Vernon-Harcourt.

He had read, with much surprise, in a French periodical¹ that M. de Lesseps, in the course of answering some questions recently put to him in America with reference to the proposed Panama canal, stated he had heard that Sir John Hawkshaw had raised objections to the Amsterdam canal. He was in a position to know that the statement was entirely devoid of foundation, and he trusted that Mr. Hayter would take this opportunity of giving it an authoritative contradiction.

Mr. HARRISON HAYTER, in reply to the correspondence, remarked that he agreed with Mr. Russel Aitken that the action of waves on an upright wall was small compared with the force exerted on a wall built on the top of a sloping bank of stone. This applied more especially to cases where the range of tide was considerable. A sea slope like that at Alderney and at Holyhead (a construction it was often desirable to follow) converted a wave of oscillation into a wave of translation, and introduced a new force. In the Amsterdam piers, however, the wave-breaker had a steep and broken slope, and was carried to within a few feet of the top of the wall, and prevented the wave forming and striking with undue force.

Mr. Harrison Hayter.

In the course of the discussion he had furnished particulars of the actual cost of the dredging. Prices that had not been given, either in the Paper or in the discussion, could not be arrived at with accuracy owing to circumstances that had been referred to. He would have illustrated more of the contractor's plant had not

¹ "Bulletin du Canal Interocéanique." May 2, 1880.

Mr. Harrison
Hayter.

the limit properly allotted for illustrations to one Paper been reached. When the Paper was read, much of the contractor's plant—especially the Titan and travelling cranes—was shown either by drawings or by photographs. The difference between the inaccurate assumed level and the actual level of the tidal range was under extraordinary conditions as much as 7 or 8 feet. It was true time was afforded for discovering to some extent that the range of tides originally furnished was not correct; but it took considerable time to prove that a wave-breaker was desirable, and to obtain the necessary sanction for such a work. The wave-breaker had added to the security of the work, and with it the breakwater had not cost a large sum of money, as he had mentioned in the discussion.

In the opinion of Mr. Dyce Cay the piers might have cost less had the design and system followed at Aberdeen been adopted, an account of which had been given to the Institution.¹ Without, however, entering into the comparative cost, Mr. Hayter would venture to say that the saving, if any, would not have been material. He had always regarded with favour Mr. Dyce Cay's method of building with concrete in large masses, but although generally applicable, it would not be so for foundation courses on fine sand subjected to the scour described in the Paper.

As regarded the use of mattresses of fascines, he concurred with Mr. Doherty that they might be judiciously copied by railway engineers in passing over doubtful foundations. He might mention that on the Great Northern railway, in the construction of which he had been engaged, the late Mr. Joseph Cubitt adopted fascine work under a long embankment which carried the railway across fens in Huntingdonshire at that time undrained. The peat was in places 20 feet deep, and a layer of fascines, or rather loose underwood, was first carefully laid and then a layer of peat was added, and afterwards a second layer of loose underwood, and then another layer of peat, and on this the embankment, which was about 7 feet above the ground, was constructed. As might have been, and was, anticipated, the embankment sank a good deal, but the plan answered perfectly. He might observe that the bridges across the fen drains were, in one or two instances, laid on a platform of timberwork placed directly on the peat. The brick abutments were built on the platform and were weighted with rails before the girders were put on. The fen had since been drained, but no difficulty had been experienced by the settlement

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. xxxix., p. 126.

either of the embankment or of the bridges. Mr. Doherty had also alluded to the circular form of the cofferdam. He could not concur in the remark that a dam having six straight sides would have been better than a circular dam. To this and to other points connected with the dam he had alluded in the discussion.

There could be no doubt that bucket dredgers, as remarked by Mr. Messent, were better adapted than sand pumps for completing work to precise levels and forms, but, for ordinary dredging in the harbour, experience proved that advantage was derived by the use of sand pumps.

With reference to the lock gates, the adoption of iron in the gates pointing seaward was out of deference to the Dutch views, as remarked by Mr. Phipps. No doubt the introduction of flat-shutting surfaces at the hollow quoins involved the difficulty of making a close contact with the sill and with the vertical face at the same time. In Holland, however, there was not any great head of water, as the rise of tide was small, and in practice no difficulty was experienced in making the gates tight. Accurate fitting was of course essential.

The accidents to the piers occurred, for the most part, either at or near the exposed ends of the unfinished structures, but finished portions elsewhere were often much shaken. The injuries were generally at and above low water. The ordinary tidal range was given in the Paper, but strong northerly and north-westerly winds caused the tide to rise 7 or 8 feet higher. Like Mr. Vernon-Harcourt, he had learnt with surprise that M. de Lesseps had stated that Sir John Hawkshaw had raised objections to the Amsterdam ship canal. It was hardly necessary to say that the reverse was the case. M. de Lesseps could only have made such a statement under an entire misconception of the facts, and he trusted that this Paper would put an end to such an erroneous, but without doubt unintentional, misrepresentation.

Mr. Harrison
Hayter.