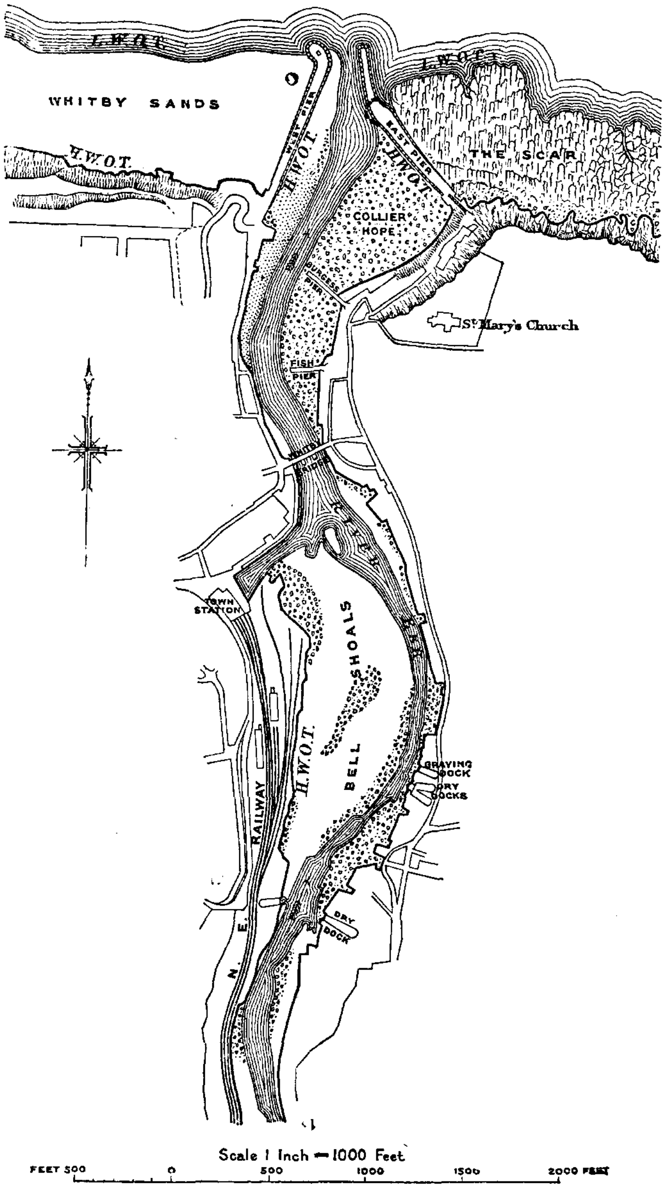
The Author. The river there was continually being driven eastward, until some extraordinary freshet burst a new channel to the sea, when the same cycle recommenced. Similarly, the River Blyth, which flowed out at Southwold, formerly had its outfall at Dunwich, 3 miles to the south. With regard to Mr. Douglass's remarks as to Littlehampton, it was well known that in the English Channel the normal drift was from west to east; but Littlehampton was one of the places where there was a false or counter flood-tide running from east to west. The Author's remarks as to Littlehampton had been submitted to the harbour-master there before being inserted in the Paper. Dr. Owens rather took the same view as the Author in regard to sand-travel. The fine particles were floating in suspension, as could be seen on any coast by reason of the change of colour when the tide ran strongly on a sandy shore. Lobster-pots were sometimes filled with sand at 30 fathoms depth, showing that the erosive action went on in deep water. Coarse and heavy sand travelled along the sea-bottom much as it did under the influence of a high wind on shore. On penetrating a sheltered area it rapidly dropped to the bottom. The scour produced by eddies, referred to by Dr. Owens, was utilized in some places to produce a slight deepening over a shallow bar. If a barge were grounded on the shallow spot as the tide was ebbing, the obstruction caused a gap to be dug out by the force of the effluent current, which might lower the bar a foot or two at the worst place. In conclusion, he echoed the remark made by Mr. Matthews as to the particular features of each locality requiring to be specially studied. As he had said before, it was that infinite variety of conditions which constituted one of the greatest charms in connection with sea-works.

Correspondence.

Mr. Austen. Mr. H. C. M. Austen thought that, as an illustration of the Author's second type of harbour—at the mouth of a river—and of the value of tidal scour as a means of maintaining a clear entrance, the case of Whitby Harbour (*Fig. 40*) might be of considerable interest. Steps had been taken in 1845 to remove the bar which had formed at the entrance of the harbour between the pier-

Fig. 40.

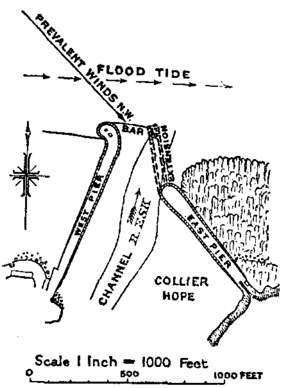
Mr. Austen.



General Plan of Whitby Harbour.

Mr. Austen. heads, as shown in *Fig. 41.* This bar, as would be seen from the plan, was formed by the meeting of the flood-tide, charged with sand, and the flow through the river-channel. The result of the meeting of those two currents was to form an eddy just inside the end of the west pier-head, and consequently slack water. This caused the sand, with which the water was heavily charged, to be deposited, and in time the deposit had taken up the position shown. Thus a vessel desirous of entering the harbour had had to go nearer the east pier in order to avoid the bar; in so doing, it had been in danger of losing steerage-way owing to the strength of the flood-tide (which flowed eastward at a considerable rate), and had tended to drift beyond the east pier-head before making the entrance. In order to minimize the trouble of the bar, some large stones had been placed NNW. of the west pier-head, below the water-level at which ships might safely enter the harbour. These stones had acted as a groyne, tending to prevent the formation of the bar by arresting the eastward progress of the sand-deposit. The remedy which had been adopted was shown in full lines in *Fig. 40*, and in dotted lines in *Fig. 41*, the object having been to bring the pier-heads both in a line parallel to the set of the tide. This had reduced the width between the pier-heads by nearly one-half, had removed the bar, and at the same time had reduced the heavy seas which formerly entered the harbour and expended their force within it. The projection of the east pier, however, caught the heavy seas from the north-west, instead of allowing them to pass. The waves, passing over shallow water, stirred up the sand, with which they became heavily charged, and swept along until they struck the inner face of the east pier extension, off which they rebounded within the harbour, where, on reaching slack water, the sand was deposited. Besides silting up the harbour, the decreased width of the mouth had made the entrance exceedingly dangerous, as, owing to the rapid cross flow of the tide, a vessel had great difficulty in shooting between the pier-heads when running before a north-west wind. She might strike the east pier-end or drift on to the rocks beyond; or, if she effected an entrance, she might collide with the

Fig. 41.



inner face of the extension. The west pier, and the old east pier before the formation of the bar, had been admirably constructed, so that a vessel might enter the harbour under the lee of the west pier, and yet, from the width of the entrance, do so without fear of losing too much steerage-way. It had been proposed by the late Mr. James Abernethy, Past-President Inst. C.E., that, after demolishing the extended arm and rebuilding the old pier-head, the harbour should be kept clear by tidal scour; in other words, by converting the inner harbour above the bridge into a tidal reservoir. He had proposed to dredge as large an area as possible between high- and low-water lines above bridge by removing the Bell shoals, and thus to increase enormously the tidal capacity of the harbour; so that the large volume of water passing in and out at every tide would have a powerful scouring action, which would maintain the channel at a fixed depth and would keep the entrance clear by removing the bar. In Mr. Abernethy's opinion, the natural shape of Whitby Harbour, which might almost be compared to an elongated bottle, was admirably adapted to the purpose; and he had considered that the alternative of converting the area above the bridge into a sluicing-basin would be valueless, where the length of channel to be scoured was so great: thus bearing out the Author's observations as to the local effect of artificial scour. Mr. Austen.

Mr. ERNEST BENEDICT observed that many years ago the late Mr. Charles Richardson, M. Inst. C.E., the Engineer of the Severn Tunnel, who lived the greater part of his life on the Wye, the Avon and the Severn, wrote a paper[1] on "Tidal Scour in Rivers," in which he affirmed that the volume of fresh water determined the size of the estuary, and that the tidal waters had nothing to do with it. The natural conclusion was that, where there was no freshwater flow, the estuary would tend to fill. Was not, therefore, the absence of any freshwater flow the main cause of the difficulty in keeping open the Madras roadstead? It had been truly observed that any backwater to a tidal harbour should on no account be curtailed. Now the backwater at Karachi, as the plans accompanying some of the Papers[2] read before the Institution clearly showed, had been seriously curtailed; first by damming the Chinna Creek; secondly, by narrowing the opening in the Napier mole; and thirdly, by not providing an inlet at or about high-water, and an outlet at or about low water, both at the mouth of the Chinna Creek, and away to the west, where only a narrow strip separated Mr. Benedict.

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[1] A copy of this Paper is in the Library of the Institution.

[2] Minutes of Proceedings Inst. C.E., vol. xxiii. p. 457, and vol. xliii. p. 1.

Mr. Benedict. the backwater from the sea. In fact, had it not been for the Layari River, there could be no doubt that the trouble due to silting in Karachi Harbour would have been enormously increased.

Mr. Bent. Mr. BALDWIN H. BENT pointed out that the chief natural conditions which affected the site at Cearà were:—(1) The great equatorial current, which struck the Brazilian coast at Cape São Roque, where it divided into two streams, one going south, the other north-west along the coast past Ceará, running about $\frac{2}{5}$ knot per hour on flood-tides, and $\frac{3}{10}$ knot on ebb-tides. (2) Great sand dunes, practically bare of vegetation and about 200 feet high, along the whole coast-line of 600 miles from Cape São Roque to Maranhão (Ceará lying between these places and 230 miles north-west of São Roque). (3) A prevailing wind from the east. Also, the coast-line for 3 miles on each side of Ceará ran almost due east and west. The larger ocean-going steamers anchored 2 to 3 miles off the town, while smaller ships and all coasting vessels lay between the Corõa Grande, or Great Reef, and the shore. The average level of this reef was about 10 feet below low water of spring-tides. As the Author had alluded to Ceará Harbour as one of the most remarkable instances of silting within his experience, the following brief history of the circumstances might be of interest. In 1874 Sir John Hawkshaw was called in by the Government to report on all the Brazilian ports, among them Ceará. Sir John no doubt noticed the natural conditions mentioned above; also that the current confined between the Great Reef and the shore was sufficient to keep clear a useful roadstead for coasting vessels. He therefore recommended that a solid breakwater should be built, more or less parallel to the shore, and connected with it by an iron viaduct 750 feet long; the breakwater itself to be 2,200 feet long (of which 1,400 feet were actually constructed). The current was to pass through the open viaduct, carry the sand along with it through the still water behind the solid breakwater and out the other side, the same as happened behind the Great Reef. There was, however, one vital difference between the breakwater and the Great Reef. The top of the breakwater was 16 feet above, while the average level of the top of the Great Reef was 10 feet below, low water of spring-tides; so that in the latter case the waves were always stirring up the water and the sand in it behind the reef. So long as the waves did this, the current was able to keep the sand moving; but when the sand came through the viaduct into the sheltered area behind the breakwater, where the waves could not act on it, it simply subsided, the current being too weak to hold it up and keep it moving at the same time. Thus the proposed deep-water harbour became a sandbank. Another thing, in the beginning, also tended to the silting, namely, there were too many piles in the viaduct; there were four rows of them, 8 feet 9 inches apart, with 30-foot spans. He had been told that as these piles were put down a tongue of sand followed them out from the shore, closing in a measure the opening that should have been 750 feet. The silting begun in this way was completed by the solid structure of the breakwater, and, sometime before work on it was stopped, the passage through the viaduct was completely closed; the sand then began to come round the end of the breakwater into the sheltered harbour. This sand did not join up to the other bank which had come through the viaduct, so that there remained a pool of water behind the breakwater, between two banks of sand. Another effect of the breakwater—a serious one at the time—was that it acted as a great groyne running out from the shore; with the result that erosion took place to leeward to such an extent that the gasworks, originally some 200 yards from the foreshore, were in danger of being carried away, and were only saved by tipping rock along the front of them. This was the position of things in 1889, when Sir George B. Bruce, Past-President Inst. C.E., was called in to arbitrate between the Harbour Corporation's engineers and the contractors. It should perhaps be stated that, beyond the original design of the harbour, which they made for the Brazilian Government, Sir John Hawkshaw's firm had nothing to do with the works. In arriving at his decision, Sir George obtained such a knowledge of the circumstances and conditions of the place that the Corporation asked if his firm would become their consulting engineers, and advise them what should be done to make the best of a bad job. Messrs. Sir George Bruce and White thereupon sent an engineer to Cearà. On arriving there this gentleman saw the danger the gasworks were in, owing to the erosion of the coast to leeward of the harbour-works, and argued, Mr. Bent imagined not unreasonably, that as the construction of these works had caused this erosion, the proper thing to do was to build a big groyne from the shore to the east, in such a position that the erosion caused by it on its leeward side should clear away the sand that had accumulated about the viaduct; and this, helped by some dredging, would clear the harbour, and make it what it was originally intended to be. Many soundings and current-observations were taken to decide on the best position and direction for

Mr. Bent.

Mr. Bent. the groyne, and this plan was finally adopted in 1891. Owing to the naval revolt in Brazil, it was not until the beginning of 1894 that a start was made on the work. At that date a powerful suction-dredger, was sent out, and was shortly followed by Mr. J. L. Houston, M. Inst. C.E., for Messrs. Punchard, McTaggart, & Co., Lowther, the contractors, and by Mr. Bent, who was resident engineer for Messrs. Sir George Bruce and White. On arriving at Cearà it was seen that the condition of things had considerably altered from what it had been reported to be 3 years before, especially about the gasworks, to leeward of the breakwater. Where the sea had then been breaking against the gasworks wall, there was a sandy beach 150 yards wide between the foreshore and the wall; in other words, the erosion caused by the breakwater was only temporary. With these additional 3 years it was easy enough to account for what had happened. The sand-laden water, travelling always in one direction along the coast, became charged with sand in two ways, namely, the sand was blown into the water by the wind, or it was taken up by the waves breaking on the sandy shore. It was important to notice, however, that the general coast-line was not much affected by this latter action, because, although sand might be taken from a particular spot by the waves and current, the same agency replaced it by a supply from the east. If, by any chance, this supply should be cut off, then the shore would be eaten away, and this was what had happened to leeward of the breakwater. For some years the sand travelling west was being used for the greater part in filling the quiet area behind the breakwater, and very little went past the works; yet all this time the waves continued breaking on the shore to leeward of the breakwater, and so eating it away, till finally, as already stated, they attacked the gasworks. Then at last, when the area behind the breakwater became filled, the supply once more began to go on past it, the artificial hole to the leeward of the breakwater began to fill, and the line of the foreshore advanced seaward to its natural position some 150 yards from the gasworks. Seeing all this, he could not but feel convinced that if the proposed groyne were built, much the same thing would happen again. The groyne would arrest the sand from the east for a time, and there would be considerable erosion to leeward of it, which would perhaps clear the viaduct; but this action would be only temporary, until the angle on the east side of the groyne was filled, when the sand would once more pour round the end and fill again the area by the viaduct: indeed, this seemed far more likely to happen here than at the gasworks, because the groyne would have the breakwater and viaduct standing out from the shore to the west of it and acting as a second groyne, whereas to the west of the breakwater the coast-line was quite unbroken. Having regard to all this, and also to the fact that there were about 1 million cubic yards more in the harbour area to be dredged than had been estimated, the engineers decided to abandon the groyne scheme, and substituted a properly fitted basin, with a narrow entrance, to be dredged behind the breakwater, making use of the pool already referred to. There was no special difficulty about this, and the scheme was gone on with. The Brazilian Government, however, who behaved very fairly throughout, were, not unreasonably, much disappointed at the idea of so small a port after the original design, and refused to sanction the plans, although their engineers were unable to propose anything more feasible. The Corporation therefore suggested that the Government should purchase the works, and this, after the passing of an Act of Congress, and many weary months of bargaining and valuing, was finally done, and the work was abandoned. The moral of the failure would seem to be, that it was not practicable to make a successful quiet harbour on such a coast, unless there was sufficient traffic to pay for the necessary dredging. Where such an amount of sand was in suspension in the water, $\frac{1}{2}$-knot currents might carry it along, so long as waves could shake it about; but so soon as it came into a sufficiently sheltered area, *e.g.*, behind a long breakwater, the sand would at once fall down, and, without dredging, the sheltered area would naturally become useless as a harbour. Under these circumstances it would seem best to construct only a low breakwater, say up to low water of extraordinary spring-tides, parallel to the direction of the current, but in no way connected with the shore; as an adjunct a jetty with good wide spans might be built out from the shore, behind the shelter of the breakwater. With only $8\frac{1}{2}$ feet range of tide, such a breakwater would make a useful shelter, though he admitted it would not be a perfect harbour. Mr. Bent.

Mr. W. DYCE CAY considered that the groyne system adopted in many parts of the south coast of England was admirably adapted to the sites and the shingle beaches. With suitable modifications it might be useful for protecting the foreshores of breakwaters constructed with rubble foundations; or break-waters might even sometimes be constructed of large rubble, with a system of transverse groynes dividing their exterior length into a succession of bays, in which the rubble might be worn by the waves but not moved away shoreward. In designing harbours, Mr. Cay.

Mr. Cay. people were often induced to believe that the effects, as to scour and maintenance of depth, produced by ebbing currents or by sluicing-basins when the harbour channel was shallow or even bare at low water, would be continued when a depth of, say, 2 to 4 fathoms at low water had been attained. This, however, was frequently not the case, as then the ebb-current, especially if it contained the fresh water of a river, flowed clear of the bottom owing to its lower specific gravity; and thus for an illusory advantage, the benefit to the navigation of width of sea-way was often sacrificed. In most cases he had been connected with, a harbour enclosed by breakwaters with their shore ends formed of open viaducts (*Figs. 8* and *17*) would not have been successful, as the sand-laden water would have passed inside, through the viaduct-openings, and would there have discharged itself, when no longer agitated by the waves. The great improvements in dredging-appliances in the last 30 or 40 years placed the maintenance and improvement of harbours liable to sanding on a much simpler basis than previously. A piled breakwater had been built at Blyth nearly half a century ago, and had been described[1] by Mr. Michael Scott in the "Proceedings." It had consisted of a creosoted pine casing filled with rubble. When Mr. Cay visited the work in 1867 some damage had occurred from the sea-worm (*Limnoria terebrans*), especially at the ends and fastenings of half-timbers; also the basket-work head was much broken, as if a ship had struck it. It stood on a reef which extended several hundred yards seaward of it, and was protected for a considerable part of its length by an old breakwater lying about 200 feet seaward. He noted that in 5 or 6 years very extensive repairs would be required by the lower timbers. It had since been replaced by a concrete structure.

Mr. Mann. Mr. I. J. MANN remarked that the movement of sand on the foreshore, and on the sea-bottom immediately adjoining the foreshore, had been the source of much trouble and expense in the construction and maintenance of many, if not the majority, of harbours; and this fact was well exemplified by the various cases to which the Author referred. Underlying the question of sand-movement was one about which very conflicting statements had been made, namely, the depth to which the disturbing action of a wave extended. There could be little or no doubt that this depth was proportional to the height of the wave measured from hollow to crest, and if this proportion were ascertained by a well-

[1] Minutes of Proceedings Inst. C.E., vol. xviii. p. 72, and vol. xix. p. 644.

arranged series of observations, it would form an item of information that would be extremely useful, and would do much to prevent the recurrence of disastrous failures, which were no doubt due to an imperfect knowledge of the laws that governed the movement of sand by the sea. With regard to the suggestion made by the Author as to the substitution of piled structures for those of solid masonry, no doubt the former could be carried out to deep water much more cheaply and quickly than the latter. There was, however, the formidable objection that the piled structure provided no shelter whatever for vessels lying alongside it, and could not be used with safety in rough weather. On the other hand, if the movements of the sand on a foreshore were previously ascertained and understood, a harbour could in many cases be so designed as to provide at moderate cost both shelter and deep water, without interfering with the natural effects of waves and currents on the bottom in shallow water; and thus the danger of shoaling could be avoided. Mr. Mann.

Mr. A. WHARTON METCALFE observed that the Author had cited in *Figs. 3–20* a possible series of interesting though troublesome cases, all probably correctly diagnosed, but for which, except in a few instances and in the conclusion of the Paper, he had not put forward any remedy. The problems met with in practice had a knack of eluding a list of typical cases. Any given case might resemble a typical one, but would differ in some important and frequently obscure particulars, which showed the futility of dealing with it on general lines; and the Paper furnished proof of the necessity of thorough and scientific methods of obtaining the data on which designs or remedial measures should be based. These data were evidently— Mr. Metcalfe.

(1) The amount and nature of the sea-borne sand or other material held in suspension by the sea-water entering and surrounding the harbour, and the amount which might enter the harbour from land water.

(2) The amount of wind-borne sand which might be deposited in the harbour from land in its immediate vicinity. In some parts of the world, notably South Africa and South America, this might be considerable, and become the dominating factor.

(3) The velocity of tidal waters outside and entering the harbour, or of fresh water entering.

(4) The direction and nature of such tidal currents.

(5) The shape of the foreshore and the material on it subject to tidal influence.

Complete information on these points would obviate much of the

Mr. Metcalfe. uncertainty which seemed to have surrounded the design of many tidal harbours on sandy coasts. In order to obtain the information, investigations must be undertaken on systematic and scientific lines, and on an adequate scale; and such investigations were necessarily costly and added to the preliminary expenses of a scheme. In large schemes such as the new Avonmouth dock or the dockization of the Avon previously proposed, the cost of the investigations was not felt. In small schemes such investigations were equally essential, even though their cost formed an appreciable item in the total expenditure; because they enabled the engineer to say with reasonable certainty whether a proposed scheme should be proceeded with or abandoned, and, if proceeded with, what modifications or additions should be made. Taking the several data seriatim, the accumulation of sand might be ascertained by measuring the deposits in fixed areas of suitable size, enclosed by planks spiked to uprights and having a level plank floor spiked to short posts driven down, or in sunken tanks. These enclosures would be placed at various points between high and low water, and the measured deposits, taken in conjunction with current-velocity observations, should furnish the required information. Where mud and sand were in suspension, or in a muddy river entering a harbour or roadstead, these data might be supplemented by taking samples of water in open-ended tubes of uniform bore, 4 to 5 feet long, attached to battens for the purpose of immersion vertically, the openings being closed by corks when the tube was full. Samples taken thus at various points along the river, at the same phases of the flood and ebb of spring and neap tides, had furnished the data for the dredging-estimates, etc., in connection with a joint report by Sir John Wolfe Barry, Sir Benjamin Baker and Mr. A. C. Hurtzig, on the question of the dockization of the Avon, upon which their opinion was sought by the Docks Committee of the Bristol Town Council in 1899. The amount of wind-borne sand might be estimated in the case of a new proposal by means of shallow rectangular flats anchored at different points along the shore, over the site of the proposed works, or mounted on posts above high-water level; in the case of harbours which were sanding up, it would be checked by deducting from the accumulated deposit over a certain period the amount estimated to have been brought in by the agency of tidal and upland water. Such observations should afford fairly reliable data. The velocity and direction of the tidal and river currents affecting any particular case were obtained by one operation, and three methods might be adopted: (*a*) a boat might be floated

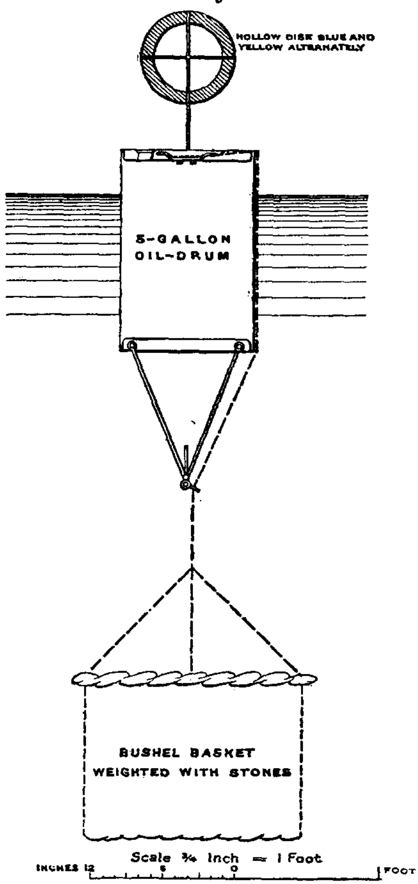
Mr. Metcalfe.

down-stream, and angular observations with a sextant be taken to three or more natural objects on shore, the time being taken by a watch: (*b*) a boat might be floated on the current, its course being booked by one of the occupants, and the time it took to pass certain transit-stations on shore at known distances apart being taken by watch. Method (*a*) was unsuitable for accurate work, especially in a rapid tideway and in any but the most favourable conditions of weather and wind. Method (*b*) was cumbersome, requiring too many boats for exhaustive observations, especially where time was short; also, the transit-stations must be fixed with some regard to convenience of measurement from each other, and might require previous careful surveying and setting out. The third method had been proposed by Sir John Wolfe Barry in connection with his report on the Bristol docks in January, 1896, for the purposes of which a number of observations of the tidal currents in King Road, at the mouth of the Severn, had been required. Briefly described, the method was the following:—A number of convenient theodolite-stations were fixed along the shore, their position being sufficiently accurately determined by a number of angular observations from each to known objects. A steam-tug anchored in a selected position beyond the highest or lowest station—according as it was flood or ebb—served as a point of departure from which a number of buoys were started at a given signal, and at prearranged intervals. Each buoy consisted of a 5-gallon oil-drum sunk to a sufficient depth to reduce windage, and kept upright by a bushel basket of stones attached to one end of a rope passed through a shackle at the end of an inverted tripod on the under side of the buoy, its other end being fastened to a cleat on the upper side of the drum, to allow of the depth of the sinker being varied. The filling-hole in the top of the buoy was closed by a wooden plug, into which was inserted a distinguishing coloured flag or semaphore, such as a painted metal disk or cross (*Fig.* 42). When started, the buoys were observed by the assistants at the theodolite-stations, and observations were taken at agreed intervals from the moment of starting, the angles being taken from the most convenient base in each case. A rowing-boat accompanied the buoy at some distance, to afford the observers some indication as to where to look for and follow the buoy when the water was choppy. One of the assistants accompanied the boat, and when by his watch—all observers' watches were synchronized at the beginning of the day—it was time to take an observation, a flag on a long pole was held up for 15 seconds, during which time the buoy was to be observed.

T 2

Mr. Metcalfe. When plotted, the results on the whole were found to be good, though towards the end of the day, when watches began to differ, they were less satisfactory, and the intersections in a few cases were not as numerous and as clean as could be wished; further, the 15 seconds during which the boat-flag was held up in order that observations might be taken was too long a time, and affected some of the results, as did also the increasing length of time it took the starting-signal from the tug's syren to reach successive theodolite-stations. In order to avoid these sources of error, as was particularly desirable in a fast tideway, he had suggested to his friend, the late Mr. J. M. McCurrich, the Engineer to the Bristol Docks, that marine chronometers should be substituted for watches, and that the observations at the start and throughout should be made at the instant the boat-flag came to the vertical, which instant was made to coincide with the pre-arranged times of observation. The results when this was done left nothing to be desired, and subsequently chronometers had always been used for similar work by Mr. McCurrich, and by his successor Mr. W. W. Squire. The form of the tidal currents, especially of inshore eddies, was greatly affected by the configuration of the coast-line, but it was unnecessary to enlarge upon this point, because, if a sufficient number of current-observations were taken on the lines described, that influence would become clearly apparent in the shape of the stream-lines, even to the extent sometimes of forming loops and figures of 8 if taken near the turn of

Fig. 42.



Mr. Metcalfe.

the tide. With regard to the nature of the material of the foreshore bed, when it was remembered how slight a current began to wear away the bottom, and that its erosive power, increasing probably with the depth, increased also with, but at a greater rate than, the velocity, as did also its capacity for holding material in suspension, it would be conceded that a case had been made out for instituting exhaustive preliminary observations of the kind described, in all cases where there was uncertainty. There were few branches of engineering in which the necessity for such observations was more emphatic than in marine and river engineering, particularly that portion of it which dealt with tidal harbours on sandy coasts.

Mr. Molesworth.

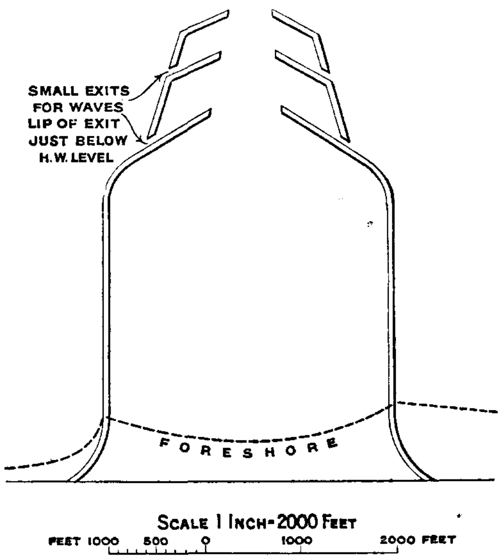
Mr. H. B. MOLESWORTH observed, in reference to the want of harbours on the coast of India, that the possibility of making a good harbour at Vizagapatam had frequently been pointed out. The principal British naval base in the East Indies was at Trincomalee on the north-east coast of Ceylon, which was a natural harbour, but was without railway communication, docks, repairing facilities, or trade of any sort. On the whole east coast of India, south of Calcutta, a length of about 1,400 miles, there was not a single port where a ship could take shelter, go alongside a wharf, or be docked or repaired. This coast was periodically visited by cyclones and exposed to the monsoon. He was well acquainted with Vizagapatam, and was of opinion that it was eminently suitable for a harbour. It was protected by a rocky headland from all southerly winds; there was a small estuary; and there had been formerly a harbour for vessels of small draught, which had been ruined by injudicious reclamation, resulting in the formation of a bar cutting off the harbour. The drift of sand was insignificant, as the sand from the south was deflected by the headland. The charts showed that there had been very little alteration of late years in the coast contours, with the exception of the local silting up on the bar. Docks, jetties and repairing shops could easily be constructed; and the port would shortly be served by three railways. The Singareni collieries would ensure a supply of coal in war-time; and the harbour could be made impregnable at a comparatively small cost. A comparatively small amount of dredging would be necessary to keep the Madras Harbour clear of sand, and he understood that a suction-dredger had been ordered for this purpose. It appeared to him that some arrangements would be advisable at Madras for ensuring the safety of the dredger in the event of a cyclone—for instance, a dock somewhat on the lines suggested by Messrs. Hawkshaw and

Mr. Molesworth. Dobson: for although he would be a bold man who would take a dredger out to sea from Madras in the face of an impending cyclone, the man who would try to ride out a cyclone in that harbour would be bolder still.

Mr. Sandeman. Mr. J. WATT SANDEMAN could not concur in the Author's statement that the effects of ground-swell and of tides were much alike, their action producing terracing. He had often observed terracing on beaches produced by wave-action, but never by tidal action. The direction of the tidal current, although parallel to the coast-line in deep water, changed in shoal water, and on sandy beaches it became nearly normal to the coast-line, when it was too slow to move sand or produce terracing. The effect of waves to which the term "ground-swell" was applied was the same as that of ordinary waves, but the former would not cause terracing unless to a very limited extent. As regarded shoaling of harbours constructed on sandy coasts, tidal currents played a very minor part in comparison with that of wave-action, and in the majority of cases their velocity was too low to move sand or to produce the effects shown in *Figs. 3–10*. On the other hand, he agreed with the Author that at all harbour-entrances on sandy coasts, wave-action would produce the effects shown by *Figs. 12–19*, although he did not agree that isolated shoals would always occur. He also agreed that artificial scour was very limited in its effect, and that depth in sand-threatened harbours must in nearly all cases be preserved by dredging, as being less costly than works capable of producing the same effect by artificial scour. The latter might, however, be found economical at harbours such as those in the Bristol Channel, having a total tidal range of 30 to 40 feet, where a much greater velocity of scour could be brought to bear upon sand at the time of low water. With regard to the formation of bars, it was evident, as stated by the Author, that the deeper the water into which entrance-piers were carried, the less difficulty there was in maintaining depth in the channel. There was a limit to the depth at which wave-action moved sand: the revision of soundings by the Admiralty, at wide intervals, showed that, generally speaking, contours of the sea-bottom at depths of about 20 feet and more below low water remained practically unchanged. Assuming that the heads of entrance-piers were carried out to 30 feet at low water, there would be little or no movement of sand from seaward, and at harbours without rivers carrying detritus there would be no shoaling. At few places, however, was it practicable—on account of the cost—to carry piers out to such a depth; and in most cases it would be more economical to maintain the required depth by dredging. With regard to Cearà Harbour, the conditions stated by the Author, Mr. Sandeman. and the contours shown by Figs. 21 and 22, Plate 4, led to the conclusion that shoaling had been due, not to the partial blocking and diversion of the equatorial current, but chiefly to stoppage of wave-action upon the area of sea-bottom sheltered by the breakwater; thereby enabling sand, lifted and drifted by wave-action, to accumulate within the sheltered area: and while the equatorial current would no doubt assist such action, yet the same would have happened had there been no equatorial current. The conditions at Cearà, as described by the Author, were such that no harbour there could be kept open, except by continual dredging; as besides movement of sand by the sea, wind-blown sand from the high dunes would quickly overtop any breakwater. He had a case in point at Blyth Harbour where sand dunes existed to the west and south; and until those to the west had been levelled down, he had had annually to dredge large quantities of sand blown into the harbour and channel. The remedy at Cearà would be to make the viaduct portion of the pier closed to the sea, which could be done economically by means of greenheart piling enclosing a rubble filling; to construct a west pier of piling and rubble filling; and to dredge. With regard to Madras Harbour, the course recommended by the Madras Committee appointed by the Indian Government in 1883, namely, closing the east entrance and providing a new entrance at the north-east end of the harbour, would give greater internal tranquillity at the least cost, although a north-east entrance would be more difficult to take in storms. A better effect could be accomplished, although at greater cost, by providing piers to act as wave-traps outside the east entrance, as shown by *Fig. 43*. These piers would reduce waves to about one-ninth of their height when they reached the harbour-entrance. Referring to the concluding remarks in the Paper, he was of opinion that if piers on a sandy coast were constructed in an efficient manner, there should be no risks incidental to them. He agreed that there were many places on the coast without harbour-accommodation where open-piled structures would supply reasonable trade facilities, and could be constructed at comparatively small cost. The whole secret of the stability of such piers lay in keeping the decking and any superstructure above the level of the crests of the highest waves occurring during the highest known tides. He had often observed the effect of seas on open-piled structures during storms, and had never seen waves strike a blow against single piles; nor had he seen or heard of an instance in which piles in an open pier, well driven, had not been able to resist the heaviest seas.

Mr. Sandeman. There were numerous positions, particularly on sandy coasts (Ceará being a very suitable example), where harbours could be economically made by means of piers, constructed of piling spaced a few inches apart and containing a filling of rubble, which, while affording efficient shelter, would not present a solid barrier to the sea. As regarded maintenance, he had constructed two such piers which had fulfilled their purpose efficiently; one being exposed to the action of the sea-worm was constructed of creosoted pine timber. It had resisted the worms for 12 years, and con-

Fig. 43.



tinued to do so. Another open pier of greenheart timber which he had constructed in the Bay of Naples had resisted the action of the *Teredo* for 18 years. Besides economy, the advantage of such piers was the speed with which they could be constructed, as there was no difficulty in building 1,000 feet of pier in a year.

Mr. Shield. Mr. WILLIAM SHIELD observed that before the Ceará harbour works were constructed, an almost identical engineering tragedy, with equally fatal results, had been enacted at Port Elizabeth, Cape Colony, as already described[1] by him to the Institution.

[1] Minutes of Proceedings Inst. C.E., vol. lxxxviii. p. 359.

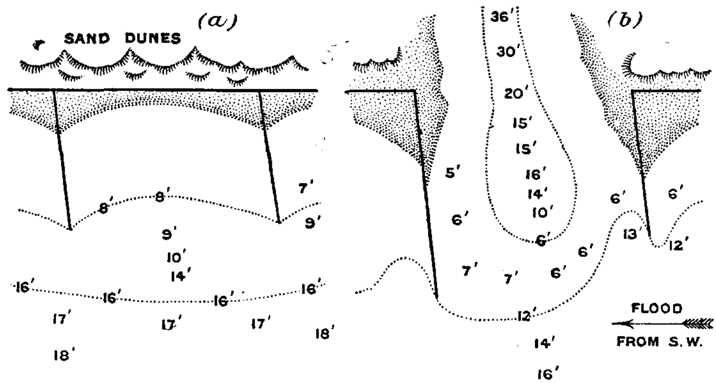
Failures such as these he believed to be largely due to imperfect or faulty diagnosis of the sites, to an inability to discern rightly and profitably the ways and workings of Nature, and to a misconception of the character and power of what were somewhat vaguely termed "littoral currents." For about 30 years he had closely watched the movement of sand on beaches in different parts of the world, and under varied conditions; and he could not but think that what might be called the "flood-tide theory" was based upon a case of mistaken identity. Where the direction of the flood-tide coincided with that of the prevailing winds, as often happened, the mistake might easily be made; but, in his opinion, the doctrine was a dangerous one, and one which, if acted upon, was likely to lead to trouble sooner or later. The evidence in support of the opposite theory, namely, that in the great majority of cases sand-travel along a shore was dominated by wave-action, was to his mind overwhelming. As a notable exception to this rule, the east side of the rock of Gibraltar might be cited. There an inshore eddy-current, which was very little affected by the tides, ran almost constantly in a southerly direction, and undoubtedly governed the direction of the sand-movement. Its velocity ranged from about $\frac{3}{4}$ knot opposite Catalan Bay to $2\frac{1}{2}$ knots per hour at Europa Point. It did not appear to move sand at all except in rough weather, when the sand was stirred up by breaking waves. Under these conditions the sea for about $\frac{1}{2}$ mile from the shore, or out to, say, the 10-fathom or 12-fathom line, was greatly discoloured by sand in suspension, which was carried by the current, as might be clearly seen, into the Straits, where it soon dispersed. With regard to Port Elizabeth, the ordinary sand-drift along the shore from Cape Recife to the town was, at the time referred to, largely supplemented—as at Ceará—by blown sand from an extensive drift to windward, which had an area of about 10 square miles. The prevailing winds were south-east and west to south-west. The south-east wind blew on-shore, and the west and south-west winds off-shore. Along the shore there was an almost ceaseless surf, which, however, was much affected by the wind. The direction of the waves, which never varied more than about two points, was almost dead on-shore, with, however, a slight inclination to the northward which was sufficient to govern the direction of the sand-travel. A strong on-shore wind set up a shore current, which in rough weather might attain a velocity of about 2 knots per hour. This current was due to two causes, namely, to the oblique wash of the waves, and to their lodging water in a temporary trough or channel which they themselves

Mr. Shield.

Mr. Shield made by drawing down sand from the beach and depositing it in the form of a bank parallel with the shore. This tripped up the waves, especially about the time of low water, and increased their power of stirring up the sand. It would therefore be gathered that during rough on-shore weather there was a very considerable travel of sand along the coast. A south-easterly gale, as a rule, was almost immediately followed by a westerly gale off-shore, which quickly altered the character of the waves, and imparted to them that subtle function or property, which was perhaps not very well understood, of heaping up the beach. Under these conditions the temporary channel, before referred to, vanished by reason of the altered wave-action moving the sandbank in-shore and again lodging it upon the beach whence it came. With the wave-wash reduced and this channel gone, the current soon ceased altogether, and sand accumulated along the shore with surprising rapidity. These were the main physical conditions affecting Port Elizabeth, a comparison of which with those at Cearà might be of interest to those who knew that port.

Mr. Siccama. Mr. H. T. H. SICCAMA considered it rather a bold undertaking to fix rules as to the displacements in a sandy bottom, due to artificial causes. There were hardly two even similar instances where the effects were the same. To mention one, there was the entrance to the new mouth of the Maas at Hook of Holland, which, it was true, was altogether due to human agency. A canal had been dug from a point on the Maas to the North Sea, nearly at right angles to the shore-line and to the direction of the flood- and ebb-currents. Before the canal was made so as to communicate with the sea, two groynes were run out as in *Fig. 44* (*a*). In 1868 the 8-foot line of soundings was more or less as in the Author's *Fig. 10*, but the 16-foot line bulged out seaward. In 1872 the canal from the river was cut, and then the contour-lines became as in *Fig. 44* (*b*). The flood tide doing most of the scouring, pools were formed at the north sides at the ends of both groynes, with depths of 12 feet. Inside this 12-foot line was a bar with 6 or 7 feet on it. Farther up the depths increased again. The soundings of 1873 and 1874 showed the same features, and they would probably have remained permanent, had not dredging on a considerable scale been then resorted to. In fact, it was only by steady dredging that a navigable channel was now kept open; and there still remained a tendency for the currents to form pools in the old places. The flood-current from the south-west, sweeping past an obstruction at right angles to its direction, formed eddies on the lee side of the end of the obstruction, and caused a deepening of the bottom there, as in *Fig. 45.* The Mr. Siccama. entrance to the harbour of Ymuiden (*Fig. 46*) was somewhat like the Author's *Fig. 18*, at least, as regarded the seaward ends of the piers. Here greater depths were sounded next to and outside the pier-ends

Figs. 44.



than farther out, the contours being very similar at both piers. This was probably owing to the fact that the flood-tides from the Channel and round Scotland met in this neighbourhood, and that their action was about equal. There was also a tendency to

Fig. 45.

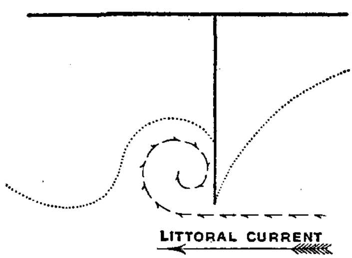
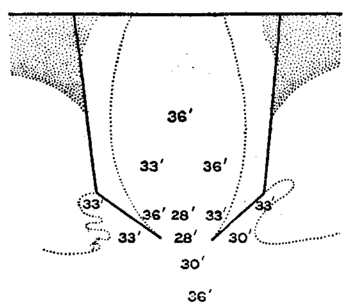


Fig. 46.

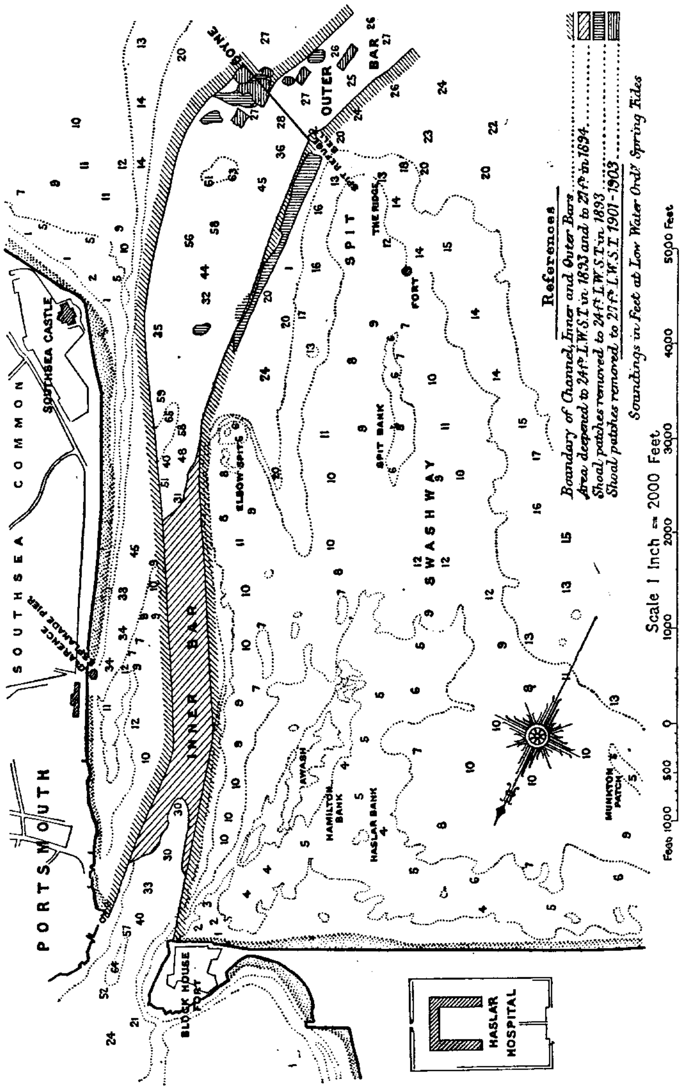


shallowing in the middle of the entrance. A good deal of dredging went on at Ymuiden also, so that there was no saying what Nature would do if not interfered with. With regard to the harbour at Madras, if the form chosen had been as shown in

Mr. Siccama. Fig. 29, Plate 4, there would probably have been less trouble with the sand, as most of it would have travelled past, instead of being held up by a jetty just laid for inviting it inside. Perhaps seafaring men would have objected, but they always did object to any devisable harbour-entrance. Yet, although they grumbled, it must be said to their credit that somehow they got in all right. The new Flushing Harbour, for instance, had an entrance nearly at right-angles to the direction of the strong flood- and ebb-currents on the Scheldt running at 5 miles per hour or more, leading into a short basin. Steamers had to rush in at full speed and then bring up in two or three times their length, if they did not want to run into a stone-pitched dam at the end, placed there as a sort of buffer-stop. This harbour was as badly designed as could be imagined; and yet the mail-steamers got in twice daily in all weathers, successfully so far.

Mr. Sims. Mr. T. SIMS remarked that to any one interested in the study of the effect of tides and of hydrographic conditions in the vicinity of harbours, the chart of Portsmouth Harbour was extremely interesting. The entrance to the harbour appeared to have been always naturally blocked by the vast "Spit" Bank and shallows covering a triangular area of about 2 square miles. The apex of this triangle was at the north, and led directly to the entrance to the harbour. The effect of ebbing and flowing tides from and to the harbour seemed to have caused a channel to be cut through the shallow bank along the north-east side of the triangle, parallel to the shore (Southsea Beach), and extending from the old town of Portsmouth to Southsea Castle, and seaward towards the Outer Bar (*Fig. 47*). The Inner Bar ran from Block House Fort in a south-easterly direction, its nominal seaward limit being its intersection with the Outer Bar on a line which joined the "Spit" Fort on the west side to the "Boyne" Buoy on the east. Records showed that the original depth of channel over the Inner Bar was very moderate. In 1860 it was increased by dredging to 13 feet at low water of spring tides in 1861 to 17½ feet, and in 1872 to 20 feet. A survey made in August, 1887, showed that the increased depth so obtained had generally been maintained. In 1891 it was decided by the Admiralty to dredge the bar to a depth of 24 feet at low water of spring tides; this work was completed in 1893. Following on this, further deepening to 27 feet was undertaken, and completed by the end of 1894. Various surveys had been made since that date, which tended to show somewhat uncertain variations in depth of water over the bar from time to time. The last survey, in 1901, showed the average depth of water to be about 29 feet at low water of spring tides. There was strong reason for hoping that the increased depths obtained Mr. Sims.

Fig. 47.



ENTRANCE-CHANNEL TO PORTSMOUTH HARBOUR.

by dredging would be maintained without much silting. It was thought that the reason for this satisfactory result might be partly

Mr. Sims. attributed to the possibly increased scour due to the considerable quantity of mud-land above low-water level which had been removed from within the harbour during the past few years; and as much yet remained to be removed, further benefits were anticipated. It scarcely seemed probable that the Inner Bar was in process of formation by a silting up of the channel. It rather appeared that this hard bank of shingle was a portion of the original shallow "Spit" Bank, which was too dense to be scoured away by the ebb and flow of the tide. This conjecture was supported by experience which had followed each dredging-operation to obtain increased depths, which showed that such depths were generally maintained. It was interesting to notice that at each end of the Inner Bar there was a deep hole of over 60 feet at low water of spring tides, which did not appear to silt up to the level of the shallower depths as might perhaps have been expected. The Outer Bar extended southward from the "Spit" and "Boyne" Buoys until deep water was met with south of the Outer Spit, a distance of about 1,300 yards to the 5-fathom line. Here the action of the currents had a very different effect, because the stream of water ebbing and flowing out of and into the harbour was no longer confined within the comparatively narrow limits of the channel, but was spread over a large water-area, with the result that the action of the currents had been found to cause a considerable amount of silting on the Outer Bar. A depth of 26 feet at low water of spring tides was maintained by occasional dredging of shoal patches consisting of very fine sand. No extensive deepening of the Outer Bar had yet been undertaken, but should such operations be carried out, the results would be extremely interesting.

Mr. Thorpe. Mr. W. H. Thorpe thought further information respecting Santa Ana harbour was much to be desired. The Author appeared to consider it surprising that the entrance had shoaled as the result of a storm, but it seemed reasonable to suppose that this harbour would of necessity be in a critical condition. The tidal capacity, estimated from Fig. 1, Plate 4, worked out at 240 million cubic feet. The flow at half-tide through the channel, calculated upon an average section of 450 feet by 76 feet by 0·75, would probably be at a mean velocity of about 8½ inches per second, or, say, 6 inches at the channel-bed, and at the narrow entrance some 50 per cent. greater. From this it appeared that no tidal scour of any importance existed. It would be instructive, he thought, to know whether the lagoon had originally been larger, and had shrunk to its present area—as a result of silting—till

Mr. Thorpe. the current through the channel was no longer able either to convey the silty matters, or to expel them if brought in bodily by storms. The diagrams of typical cases might be of real service in helping to separate the effects of influences at work in more complex cases. Effects produced by causes acting from a considerable distance were, he submitted, at times apparent. As an instance of this might be cited, if the reasoning were accepted, what had happened in the vicinity of the mouths of the rivers Mersey and Dee, since the Mersey bar had been dredged. Within the rectangular area of which the Lancashire coast formed part of the eastern side, and the Cheshire coast part of the southern side, containing about 120 geographical square miles, there had been during the last 11 years shoaling amounting in the aggregate to fully 250 million tons, and a sensible accretion to the banks on either side of the main channel, with here and there some reduction. The result of dredging about 50 million tons appeared to have been, by providing freer passage of tidal water through the bar, to reduce the velocity in approaching and passing over the banks, when these were covered, thus permitting the deposition of silt in large quantities. There had also been a considerable sanding-up of the Rock channel, and some alteration, both by accretion and reduction, of the Hoyle banks. The effect of the dredging, he suggested, extended a distance of 9 miles in a direct line, or measuring along the main channel, the Rock channel and across the Hoyle banks, a distance of 17 miles; and he thought it probable these changes would become more marked till the Rock channel became blocked for some time after low water, with the ultimate consequence of the eastern arm of the Dee breaking through the East Hoyle bank and re-establishing Hoylake, which 200 years ago was a wide and deep channel. That Hoylake did not become closed, and would not of necessity remain so, as an after-result of works carried out in the upper Dee in the early part of the eighteenth century, was evidenced by the fact that the first part of those works, the diversion of the Dee river through a new cut 10 miles long, was not brought into use till April, 1737,[1] whereas the Hilbre channel had broken through the Hoyle bank and Hoylake was in process of closing previous to that date, as shown on a chart dated 1736. In conclusion, he ventured to think it probable that dredging on the Mersey bar might later have become little, if at all, necessary

[1] T. Baines and W. Fairbairn, "Lancashire and Cheshire: Past and Present," vol. ii. p. 98. Lond. 1869.

Mr. Thorpe. where now carried on, for the maintenance of the 27 feet depth, though a new bar would probably form in deeper water, which might or might not be kept down by dispersal in the more exposed situation.

Mr. Vernon-Harcourt. Mr. L. F. VERNON-HARCOURT remarked that the subject submitted by the Author was of great importance, and surrounded by difficulties. A Paper on "Harbours and Estuaries on Sandy Coasts" was read at the Institution 22 years ago,[1] and perhaps, owing to the lapse of time, was unknown to the Author, as he had not alluded to it; but the discussion and correspondence on that Paper, which raised the various points with which the Author had dealt, should not be allowed to be buried in oblivion, for several eminent engineers who had taken part in that discussion had since passed away; and out of eighteen persons who joined in the correspondence, thirteen were foreign engineers having special experience on the subject in Holland, Belgium, France, and Italy. Two important and elaborate publications had appeared since then, on the formation and maintenance of harbours upon sandy coasts, which might be consulted with advantage; one in 1889, by Mr. Eyriaud des Vergnes,[2] the engineer who introduced suction-dredging, in place of sluicing-basins, for maintaining and deepening the approach to Dunkirk Harbour; and the other in 1894, by the late Mr. P. de Mey,[3] who initiated the improvement of the access to Ostend Harbour by dredging channels across the Stroombank, to which the Author had referred. In his references to Dunkirk, Ostend, and Madras harbours, the Author necessarily traversed similar ground to that of the earlier communication, with the addition of subsequent particulars, and instances of harbours recently constructed or proposed; and the most novel features of his Paper were his diagrams of the effects of littoral drift under different conditions, and his proposal to evade the difficulties of maintaining harbours upon sandy coasts, and the expense their construction and maintenance entailed, by resorting to open pilework piers for the discharge of cargoes at towns on the sea-coast. *Figs. 3–20* appeared to be based on the Author's views of the effects the littoral currents, due to tides and wind, produced on a sandy foreshore, when solid obstructions, or the discharge from rivers, impeded their progress; for no instances were cited in

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

[2] "Étude sur l'établissement et l'entretien des ports en plage de sable," *Annales des Ponts et Chaussées*, 6th series, vol. xvii. p. 185.

[3] "Étude sur l'amélioration et l'entretien des ports en plage de sable et sur le régime de la côte de Belgique." Paris, 1894.

Mr. Vernon-Harcourt.

support of them. The accretion shown in *Figs. 10* and *19* might, indeed, be regarded as approximately correct, and also the absence of accretion in *Figs. 11* and *20* with an open viaduct or pier; but the others, showing outlying shoals, appeared open to question. Undoubtedly a bar was found in front of a river-outlet or jetty channel, somewhat in the positions occupied by the shoals in *Figs. 3–6* and *Figs. 12–15*; but a bar, instead of being a shoal rising, as shown, above low water, was really a part of the outlet-channel across a shallow foreshore, where the issuing current, in gradually losing its scouring efficiency, was not able to maintain as deep a channel as near the outlet, before reaching deep water outside; and the depth over the bar was greater than that on the foreshore on either side of it. The tendency, indeed, of the checking of the littoral currents by the discharge from a river or jetty harbour, at right angles to the coast, was to raise the foreshore somewhat on each side of the outlet-channel where the littoral currents were fairly equal in both directions, as at the mouth of the Maas; and on the windward side of the channel with a prevalent wind in one direction, as evident on the northern side of the Yare outlet, and the western side of the approach-channel to Dunkirk Harbour. The diversion also of the outlet of rivers with a small tidal and freshwater discharge, was clearly due to the accumulation of drift on the windward side of the outlet-channel, and to this drift being driven along the coast by the strong prevalent winds, so as to force the outlet to travel to the leeward, till the discharge could find an escape through a weak place in the beach, or the increase of the tidal volume in the lengthened channel, aided in some cases by a leeward jetty across the foreshore, gave the discharge sufficient scouring power to form a permanent outlet in spite of the drift. Moreover, at the outlet of a lagoon harbour such as Poole, of which he had recently examined all the principal charts extending back to the eighteenth century, there were no signs of a detached shoal in front, as shown by the Author in his diagrams; but the outlet-channel, which was deflected by the south-easterly winds to which it was mainly exposed, gradually shoaled to a bar before reaching deep water, on which, however, the depth was greater than on the adjacent sandbanks which bordered the outlet-channel.[1] In the various charts of sandy bays which he had examined, there was no evidence of a central outlying shoal, such as was shown in *Figs. 6, 7, 15*, and *16*. It seemed

[1] L. F. Vernon-Harcourt, "Report on Poole Harbour Protection." Poole, 1903.

Mr. Vernon-Harcourt. also hard to understand, on comparing *Figs. 9* and *18*, why the effect of the addition of the action of a prevailing wind to the tidal littoral drift, in *Fig. 18*, should reduce the amount of accretion on the outer side of the windward breakwater, instead of increasing it; or why it should obliterate the curious, central, detached shoal shown inside the harbour in *Fig. 9*, and produce an increased quantity of silting inside the harbour? As the Author observed, there were two main types of harbours upon sandy coasts, the one chiefly natural, extending inland and having a narrow outlet on the sea-coast, and the other artificial, formed by one or two breakwaters carried out across the sandy foreshore of the open sea-coast. The first type consisted of lagoons, or wide expanses inland below sea-level, into which rivers flowed near the sea-coast, such as Christchurch, Wexford, and Poole harbours, and the ports of Calais, Dunkirk, and Ostend, whose outlet-channels had been guided by jetties across the beach; and, lastly, distinct river-outlets giving access to ports inland, in which the freshwater discharge might exercise an important influence, as in the case of the outlet of the Maas across the Hook of Holland. Lagoon harbours, and the jetty harbours of the North Sea coast, had maintained a good depth in past times at their outlets, mainly owing to the scour of the tidal ebb and flow emptying and filling extensive areas shut off from the sea by sand dunes; but gradual silting in the lagoons, from the flood-tide bringing in sand which the ebb-tide did not wholly carry out again, had often diminished the tidal scour by degrees, and, consequently, the available depth over the bar at the outlet; while extensive reclamations, as carried out in Wexford Harbour, and especially at Calais, Dunkirk, and Ostend, had greatly reduced the tidal scour through their outlets. An effort had been made at these latter harbours to restore the tidal scour, by forming sluicing-basins in the lowlying land adjoining the entrance, which were filled by the rising tide, and emptied at low water; but a bar had remained in the outlet channel seaward of the entrance, in an awkward position both for navigation and removal; and, accordingly, in 1875 suction-dredging was commenced in the outlet channel at Dunkirk, to assist the tidal scour, at a cost of 1*s.* 9*d.* per cubic yard, which had been reduced by 1882 to slightly under 3*d.* In proportion as the expenses of suction-dredging had been lowered, the operations had been extended, and the sluicing-basin at Dunkirk had been replaced by docks; while suction-dredging had also been resorted to for deepening the outlet channels at Boulogne, Calais, and Ostend, far beyond the limits attained by scour from the sluicing-basins. In fact, as

Mr. Vernon-Harcourt.

stated by Mr. Eyriaud des Vergnes at the Paris Navigation Congress in 1900, sluicing-basins had now been quite abandoned in France in favour of suction-dredging;[1] and the construction of the new sluicing-basin at Ostend[2] was regarded by French and Belgian engineers as the last relic of antiquated views. The Author appeared, from his remarks on p. 6, to have not quite rightly appreciated the object of dredging the eastern channel across the Stroombank, near the entrance to Ostend Harbour, which was clearly stated in Mr. P. S. Van der Schueren's Paper[3] on the works at Ostend Harbour, read before the Third Section of the Paris Congress of 1900. The flood-tide running up along the edge of the Stroombank, in a north-easterly direction, had been gradually silting up the north-eastern end of the channel running past the entrance to the harbour, between the Stroombank and the shore, thereby tending to connect the bank with the coast, and had thus been checking the run of the flood-tide along the inshore channel,[4] which action had been producing a shoaling of the channel in front of the entrance. The eastern channel had, accordingly, been dredged to open out again the inshore channel at its north-eastern end, restoring the condition shown on the chart of 1804, and thereby preserving the scour of the tidal currents through this channel. When an artificial harbour was formed by breakwaters extending out across the foreshore to deep water on a sandy coast along which there was a littoral drift, these breakwaters naturally acted as groynes in arresting the drift, and produced an advance of the foreshore. This was manifested by an advance of the beach and of the lines of soundings to a moderate extent on each side of Ymuiden Harbour at the North Sea entrance to the Amsterdam Ship Canal; by a considerable progression of the sandy foreshore on the western side of the west breakwater at Port Said; and by the unexpectedly rapid advance of the shore on the southern side of the south breakwater of Madras Harbour, so that now the travel of sand from the south had overlapped the outer end of this breakwater and commenced silting up the entrance at the rate of 1 foot per annum. The advance of the foreshore at Ymuiden appeared to have reached its limit, and at Port Said had become quite slow; and the silting inside these harbours and at their outlets was removed periodically, without difficulty, by dredging. At Madras

[1] VIII^e Congrès international de Navigation. "Compte rendu des Travaux." Paris, 1900, p. 500.

[2] Minutes of Proceedings Inst. C.E., vol. cxxxvi. Pl. 6, Fig. 17.

[3] "Travaux . . . à l'atterrage et au port d'Ostende," p. 4.

[4] P. de Mey, "Ports en plage de sable," Atlas, Pl. 8.

Mr. Vernon-Harcourt. the drift of sand from the south was quite exceptionally large; and there appeared to be some danger that the travel of the sand, after passing the outer end of the harbour and proceeding northward, might impede the access to the proposed northern entrance by the sand being deposited under shelter of the projection of the harbour beyond the proposed sheltering breakwater. The Author was mistaken in attributing the abandonment of St. Catherine's Harbour, Jersey, to its obliteration by sand-drift. When resident engineer at Alderney Harbour, Mr. Vernon-Harcourt had also had St. Catherine's Harbour under his charge, and he had visited it on two or three occasions. The works were stopped after the completion of one of the breakwaters, because, as stated in his Paper on Alderney Harbour, "the Admiralty decided that the harbour was not required, and should be abandoned."[1] He was unaware of the present condition of St. Catherine's Bay; but, though some silting up had occurred in the bay when he visited it 15 years after the termination of the works, as the natural result of the projection of a single breakwater like a groyne, the sections he then took across the rubble mound of the breakwater towards the outer end, showed a depth on the inner side of the breakwater of 35 feet at low water of spring tides and 67 feet at high water;[2] and therefore, even at that time, the harbour could not be described as obliterated by sand-drift. The Author, after indicating in *Figs. 8* and *17* his views of the effects of carrying an open viaduct across a sandy foreshore, before commencing a solid sheltering breakwater, gave Ceará Harbour as an example of this form of breakwater, exhibiting results entirely at variance with his theory. Rosslare Harbour, however, on the east coast of Ireland, a few miles to the south of Wexford, of which he had superintended the commencement,[3] and which, after being stopped for many years for want of funds, had recently been extended with successful results, was a more favourable example of this type of construction. Zeebrugge Harbour, in course of construction in the North Sea at the entrance to the Bruges Ship-Canal, was another instance of a sheltering breakwater approached by an open viaduct across a sandy foreshore, subject to littoral drift;[4] and the results of this work, designed to avoid the deposit of drift inside the harbour

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[1] Minutes of Proceedings Inst. C.E., vol. xxxvii. p. 75.
[2] *Ibid*, vol. xxxvii. Pl. 6.
[3] *Ibid*, vol. lxx. p. 50.
[4] *Ibid*, vol. cxxxvi. p. 285; and vol. cxlv. p. 319.

Mr. Vernon-Harcourt.

when completed, would be of considerable interest with reference to the maintenance of harbours on sandy coasts. All the methods of construction of harbours on sandy coasts referred to in the present Paper, had been mentioned and had found advocates in the discussion and correspondence on the earlier Paper; and in his reply to the correspondence, he had summed them up as follows: "(1) The jetty system; (2) Closed harbour with converging solid piers; (3) An outlying, detached solid breakwater; and (4) One or more sheltering breakwaters connected with the shore by one or two open viaducts."[1] A detached breakwater, parallel to the shore, had not as yet been constructed in front of a sandy coast, with the object of providing shelter without impeding the travel of drift; but this system had been suggested for Ostend,[2] and had been proposed, as shown by the Author, for some harbours in Denmark. The last form of harbour had hitherto been restricted to a single open viaduct, stretching out across the foreshore, leading to a solid breakwater curving round and extending parallel to the shore. The construction, however, of an outlying harbour, protected by breakwaters and connected with the shore by a viaduct, on the principle of *Fig. 26*, had been suggested by Mr. Redman for sandy coasts like those of Belgium, and had been mentioned by Dr. Pole as proposed by Mr. Dupuy de Lome for Calais, in the discussion on the earlier Paper in 1882; and he had himself, in his reply to that discussion, besides alluding to Sir Andrew Clarke's scheme for Madras, resembling in principle Rosslare Harbour and the design for Port Elizabeth, referred to a design he had seen for Madras Harbour, in which the only difference from *Fig. 26* was that the inner breakwater was curved as well as the outer.[3] Nevertheless, though no novel principle had been evolved for the construction of harbours on sandy coasts in the 22 years which had elapsed between the two Papers, the Author had rendered a valuable service to the Institution in bringing forward again this interesting subject for discussion, in a Paper which furnished several new examples. The chief change in practice which had occurred in this period was the practical abandonment of sluicing-basins, and the general adoption of suction-dredging; and the gain in experience was the success which had attended the lowering of bars, and the deepening of approach-channels, by sand-pumps at a moderate cost, and the great drift of sand along the coast which took place in certain localities, as exemplified by the shoaling

[1] Minutes of Proceedings Inst. C.E., vol. lxx. p. 100.
[2] *Ibid*, vol. lxx. p. 87.
[3] *Ibid*, vol. lxx. pp. 41, 45, 49, and 52.

Mr. Vernon-Harcourt. at Madras and Cearà harbours. The accumulation of sand against the south breakwater at Madras, where the tide was feeble, and also against the west breakwater at Port Said, where there was no tide, demonstrated forcibly the predominant influence of the prevailing winds in causing littoral drift; though in the absence of wind, the somewhat greater power of the flood-tide than of the ebb, except where counteracted in rivers and estuaries by the freshwater discharge, should produce a moderate travel in the direction of the flood-tide. In conclusion, though it was impossible to build harbours on any site where funds were not available, and where there was little trade to afford a return on the expenditure, there appeared to be no reason to abandon the construction of harbours on sandy coasts where they were really required, except possibly at such exceptionally unfavourable sites as Madras and Cearà. Jetty harbours, deepened and maintained by sand-pump dredging, provided valuable facilities for passenger traffic and trade, as exemplified by Calais, Dunkirk, and Ostend, and also the outlets of rivers guided by jetties across a sandy foreshore, regulated by training-works, and improved by dredging, as illustrated by the Maas, the Tyne, the Tees, and various other rivers. Closed harbours had proved very satisfactory, even in somewhat unfavourable localities, such as Ymuiden and Port Said; and an outlying breakwater approached by a viaduct across a sandy foreshore, afforded a fair prospect of successful results under ordinary conditions. An outlying harbour enclosed by breakwaters would necessarily be very costly; but possibly a detached breakwater parallel to the coast might, under certain circumstances, provide adequate shelter to landing places and quays adjoining the shore, without impeding the littoral drift.

Mr. Voisin. Mr. Voisin, of Boulogne-sur-Mer, believed that, in the main, the views so ably put forward by the Author were incontrovertible. They were, however, perhaps a trifle too generally stated, since, in addition to the currents produced by the ebb and flow of the tide, the velocity of these currents, the calibre of the sand-grains, and the predominating winds, it appeared to him to be particularly necessary to take into account the slope of the sea-bottom in the vicinity of the coast, and certain other local conditions. These could not all be so far included as to render it possible to formulate, as the Author had done, a set of laws which would be generally applicable. It was, in fact, necessary to investigate in each particular case whether there might not be certain special circumstances to which more or

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less weight should be attached. The depth of water shown at Boulogne presented an interesting exemplification of this twofold aspect of the subject. In conformity with the laws laid down by the Author, the general drift of the sand tended to take place from south to north, consequent upon both the superior velocity of the flood-tide and the prevailing direction of the winds, which blew along-shore either from the south or west; and thus, since the completion of the Carnot breakwater in 1889, there had been a considerable accumulation of sand against the weather side of the pier and a corresponding denudation to leeward, that was to say, on the eastern side of the Boulogne coast-line. As would be evident from the accompanying profiles (*Figs. 49*), however, the shoaling was confined to depths of 4 to 5 metres (13·1 feet to 16·4 feet) below datum in such a measure that there would seem to be but little likelihood that any important part of the spit of the foreshore or of the base of the pier would be silted up; on the contrary, the soundings tended to increase in depth towards the outer extremity of the piers (*Figs. 48* and *49*). The reason of this was, as had been foreseen at the time the works were planned, that in this part of the offing they were being placed on the summit of a submerged cliff, the upper part of which was 8 to 10 metres (26·2 to 32·8 feet) below datum, having steeply sloping sides reaching down to a hard bottom at 15 to 20 metres (49·2 to 65·3 feet) below datum. These cliffs constituted the banks of a veritable submarine river, which had been, so to speak, in no way interfered with by the above-mentioned works; and, owing to the depth of its banks and the nature of its bed, this river conveyed but little sand. This was, in fact, an illustration of special local circumstances needing consideration, to which he had previously alluded. While, therefore, the general accuracy of the conclusions arrived at by the Author was established, namely, that tidal sea-ports could be maintained free from sand only by dredging, there might yet be peculiar local conditions under which the amount of this dredging might vary very considerably. This might be what the Author had implied at p. 219 of the Paper. Such was the case at Boulogne, since the ordinary maintenance of the requisite depth of water in the port entailed the removal of rather more than 360,000 cubic metres (470,880 cubic yards) annually, at a yearly cost of about 70,000 francs (£2,800), which, in view of the results obtained, did not appear to be extravagant. It was, moreover, necessary to state that a considerable part of these deposits originated from the solid matters discharged by the sewers of the town into the inner harbour, and from the erosion

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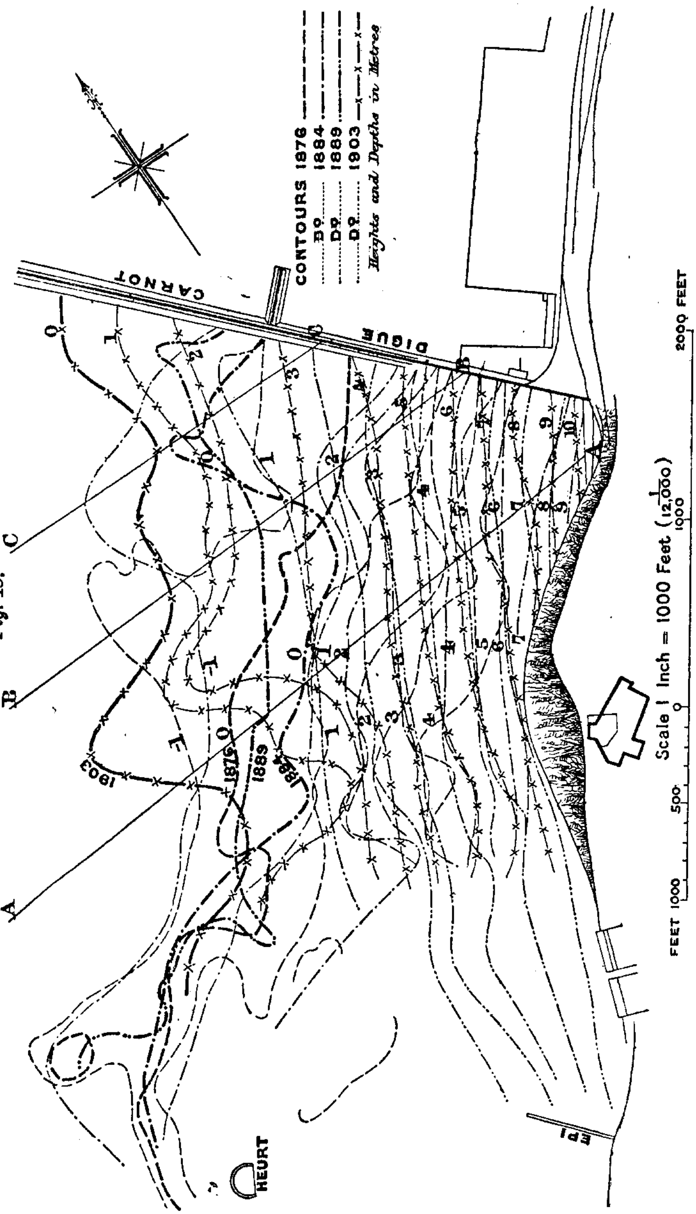
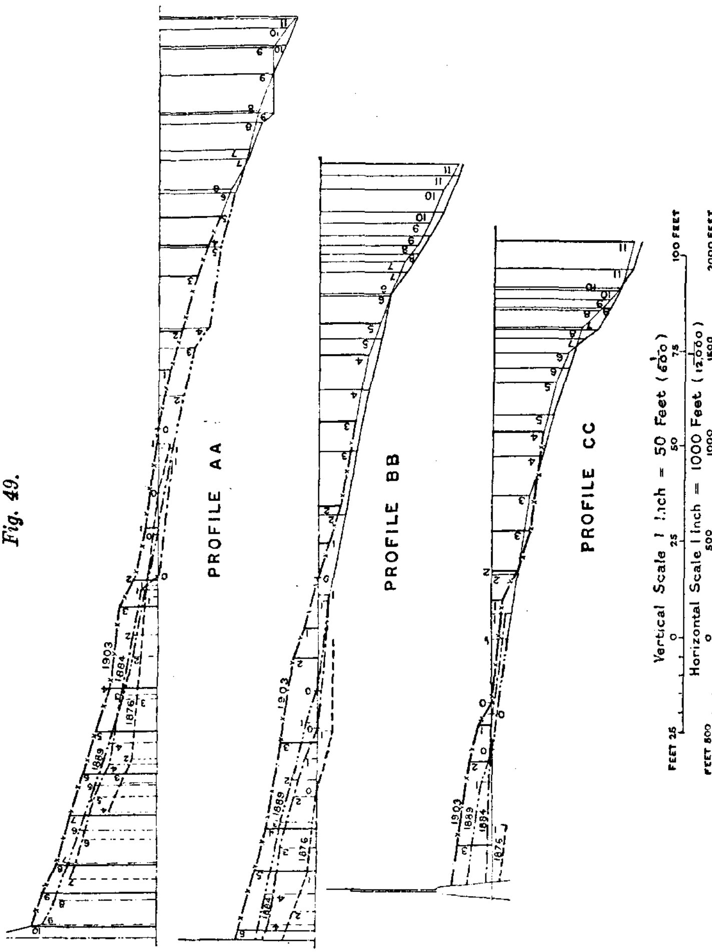
Fig. 48.



Contours of the Foreshore at Boulogne-sur-Mer, 1876–1903.

produced in the narrow torrential valley of the River Liane, which flowed into the port. A further example, which corroborated the facts represented by *Fig. 20*, was furnished by the little sea-wall at Le Portel, a port situated about 5 kilometres (3·1 miles) to the Mr. Voisin.

Fig. 49.



PROFILES OF THE FORESHORE AT BOULOGNE-SUR-MER, 1876–1903.

south of Boulogne. This pier, which had been pierced with a series of openings, had not sensibly modified the soundings in its vicinity, and had nevertheless had the result of producing a very appreciable amount of shelter on the coast of Le Portel, as desired.

Mr. Wheeler. Mr. W. H. WHEELER remarked that the intention of the Paper, as expressed by the Author, was to show how littoral drift along a coast tended to sand up harbours, but the examples (*Figs. 3–20*) of the effects of various forms of breakwaters for the purpose of providing against this, and for maintaining a depth of water sufficient for navigation, appeared to be purely theoretical. If examples had been taken from existing harbours, they would have been much more instructive. In a Paper,[1] which he had presented to the Institution in 1895, he had contended that if breakwaters were carried out from the coast into water of sufficient depth, the channels would be free from the action of the littoral drift and be beyond the local influence of matter drifting along the coast, and would maintain their depth. The least depth that had been found sufficient in practice was 2½ fathoms, and sand and shingle never drifted round the end of a breakwater terminating in a depth of 4 fathoms. Several examples of existing harbours were given in the Paper, some of which fulfilled this condition and were successful, and others which had not failed to maintain deep water. It was also shown that although the extension of a breakwater out from the coast where there was much drift resulted in the accumulation of material on the windward side, this deposit ceased after it had extended out for a certain distance; owing to the supply being cut off by the protection afforded to the cliffs by the raised beach, or, in the case of a sandy beach, by the slope becoming so steep that sand put in motion by the waves was carried out to sea during the receding of the tide, and did not drift along the shore. He was also of opinion that the maintenance of depth in a breakwater channel was facilitated by giving it a slightly curved form, the line of curve extending away from the direction from which the drift came. The scouring action of both flood- and ebb-tide was thus increased by running round the inside of the curve, and the deepest channel was always maintained in one place; the force of the water was also concentrated on any deposit that tended to collect and form a bar at the end of the piers. The curved form also, while forming no obstacle to the approach, covered the entrance and afforded shelter within. In some cases a single curved channel on the windward side of the entrance had been found sufficient to maintain a deep-water channel and prevent the formation of a bar. The Author in his examples had not dealt

[1] "Littoral Drift: in its relation to the Outfall of Rivers, and to the Construction and Maintenance of Harbours on Sandy Coasts," Minutes of Proceedings Inst. C.E., vol. cxxv. p. 2.

Mr. Wheeler.

with channels of a curved form. The example of the harbour at Curaçao appeared to confirm these views. The mouth of the harbour was in 15 fathoms of water, and along the channel, which was slightly curved, the depth was 10 to 13 fathoms, while in the lagoon with which it communicated there was only 6 to 8 fathoms. At Ceará the depth was stated to be 3 fathoms, and the sea with which it communicated was so shallow that only 5 fathoms was reached at 3 miles out. With such shallow water failure seemed to have been invited by making the breakwater open next the shore, thus allowing the sand drifting along the coast to pass through this open work into the channel. It did not, as the Author stated, outflank a solid barrier, but passed through the open viaduct into and across the channel.

The Author.

The AUTHOR, in reply, was fully in accord with the final decision against the proposal tentatively put forward by the late Mr. James Abernethy to convert the River Esk at Whitby above bridge into a sluicing-basin, as described by Mr. Austen. The only effect would have been, in his judgment, to dig a pit immediately seaward of the bridge, and to leave the harbour-entrance probably in a worse state than if scour had not been attempted. He thought the port might be materially improved at small cost by the construction of an open-piled pier on the east side. He had not seen Mr. Richardson's paper referred to by Mr. Benedict. The size of an estuary and the volume of its freshwater discharge were obviously correlative, and the configuration of an estuary was thus largely moulded by the effluent. Mr. Bent's statement as to Ceará Harbour proved that delay on the part of the Brazilian Government had prevented the adoption of a measure which might have resulted in greater complications than those actually experienced. The projection of a solid groyne to windward of the harbour would necessarily have produced erosion to leeward of such groyne. When the altered contour of low-water line, due to the new obstruction, became permanent, the drift of sand would have resumed its previous travel, and, gorging having taken place, fresh accretion along the frontage of erosion would have resulted. He understood from Mr. Dyce Cay's remarks that he advocated a system of groyning on the outer side of breakwaters built of rubble. Such groynes, or spurs, would be almost as costly to construct as corresponding lengths of breakwater, and should surely be unnecessary. The Author of course did not propose the abandonment of harbour-construction on the lines of established practice. His contention was that in many instances a piled structure could be designed at a fraction of the cost of a solid breakwater, and give

The Author. reasonable trade facilities. It seemed to him misleading to induce a Government or local authority to embark on the construction of a harbour so designed that the inevitable result must be either sanding-up, or permanent expenditure for dredging, unless those factors were previously clearly defined. With regard to Mr. Mann's statement as to the incompleteness of the facilities provided by a piled structure, these were admitted; but he thought the actual results attained at Port Elizabeth, Cape Colony, and detailed by Mr. Shield, furnished a sufficient justification for the suggestions contained in the Paper. He was entirely at one with Mr. Metcalfe as to the necessity of exhaustive data before any harbour-works could be satisfactorily laid out. Such information as could be obtained from local fishermen and others was often unreliable. If their preconceived theories came into collision with facts it was frequently the worse for the facts. One source of possible miscalculation in the studies for sea-works was the difference between superficial and bottom currents. Mr. Molesworth's remarks as to the coast of India emphasized the views of the late Sir Andrew Clarke. His statement[1] was—

> "They had between Calcutta and Bombay a coast-line of 2,300 miles, in which a steamer could not go alongside a wharf to discharge its cargo. That was a disgrace both to the Government of India and to this country. Due to this want of communication he had no hesitation in saying that, in the famine of 1877–78, no less than between three and four millions of their fellow-subjects perished."

The Author fully agreed with Mr. Sandeman that wave-action was the primary cause of sand-movement; but the sand once being stirred up by the waves, and thus in suspension, it was capable of being transported by a comparatively feeble tidal current. The Author's remarks as to terracing under the action of ground-swell had reference to the terracing of beaches, not of sand. With an oily sea and ground-swell dead on, this action was pronounced and rapid. It might be stated generally that on an undisturbed coast-line there was little or no movement of sand along a sea-bottom beyond a depth of 24 feet, but when solid works were projected into the sea, as was evidenced at Madras, these effects took place at much greater depths than this. He doubted whether Mr. Sandeman's suggestion of wave-traps for Madras, as shown in *Fig. 43*, would be an improvement on the original design. Their effect would be to plough up the sand near the entrance to the harbour, and they would also result in a gorging of the water

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[1] International Maritime Congress, 1893. Proceedings of Section I. p. 172.

in the harbour itself. It was obvious from the graphic description given by Mr. Thorowgood of the harbour of Madras in a cyclone, that this gorging, which had raised the level of the water inside the harbour to a higher level than that outside, had, in the cyclone which wrecked the harbour, caused the sea-walls to fall outwards. With regard to Mr. Thorpe's reference to St. Ana Harbour, the hurricane on record previous to that of 1877 took place in 1807, and the Author believed that the general conditions, both as to the lagoon and the harbour-entrance, had remained practically constant up to the sudden narrowing of the latter in 1877. In reply to Mr. Vernon-Harcourt's remarks, the Author was not aware of any discussion on the question of Madras Harbour at the Institution, although the ports of Dunkirk and Ostend had been referred to on previous occasions. The diagrams *Figs. 3–20* were put forward to illustrate the effects of the littoral forces. They represented types of normal harbours and harbour-entrances, and illustrations of them would readily suggest themselves—most readily to Mr. Vernon-Harcourt. Citing instances in each case would have resulted in a very voluminous Paper; and many illustrations had been referred to during the discussion. The Author did not intend to imply that the shoals marked on *Figs. 3–6* and *12–15* would necessarily be visible above low water, but that the tendency to shoal would be in the localities indicated. His view appeared to be supported by Mr. Vernon-Harcourt. There was no doubt that in a harbour as shown in *Fig. 18* the littoral drift on the windward side would tend to accretion, as compared with that in *Fig. 9* under tidal effect only, and conversely on the leeward side to denudation. With regard to the reasons for the cutting of the eastern channel across the Stroombank at Ostend Harbour, Mr. Van der Schueren's actual statement[1] was:— The Author.

"Les dragages qui s'exécutent ont pour but de couper la jonction qui s'est opérée graduellement depuis un siècle et de créer une nouvelle situation se rapprochant de la configuration hydrographique accusée par les plans de sondages dressés en 1801. Sur ces plans figurent des profondeurs de 8 mètres sous marée basse de vive eau ordinaire, là où en 1897, époque qui marque le commencement des travaux, on ne sondait guère plus de 4 mètres. Ainsi que les études de feu M. l'ingénieur en chef de Mey l'ont montré, c'est à l'action des courants de marée qu'on doit attribuer le comblement progressif de la dépression séparant le Stroombank de la côte. Au moment de son maximum d'intensité, le courant de flot suit une direction sensiblement parallèle à celle du banc. En s'appuyant sur le talus Nord du plateau, il entraîne peu à peu les sables le long de celui-ci. L'action combinée des courants de marée se traduit par un déplacement définitif des sables vers le Nord-Est, sous l'effet

[1] "Travaux . . . à l'atterrage et au port d'Ostende," p. 4.

The Author. prédominant du courant de flot; et par la formation de dépôts à l'extrémité correspondante du banc. La modification qui s'est produite ainsi dans la configuration du Stroombank n'a pas laissé d'exercer son influence sur la situation des profondeurs dans la petite rade. Celle-ci s'est trouvée soustraite, dans une certaine mesure, à l'action des courants de marée se propageant moins librement entre le Stroombank et la côte. De là une tendance à envasement dans cette partie de l'atterrage."

From this it would appear that the shoaling of the Petite Rade between the Stroombank and the coast-line was primarily the reason for cutting the eastern channel. With regard to St. Catherine's Harbour, the Author had always understood that it was abandoned by reason of a change of policy. Having had occasion to report a few years back upon the capabilities of a point on the Jersey coast contiguous to St. Catherine's for harbour purposes, he had noted that low-water line at St. Catherine's had been projected seaward, so that a length of more than three-fourths of the breakwater was sanded up. Mr. Vernon-Harcourt's remarks as to Cearà were not quite inferential from the Paper, as the length of open viaduct in the structure bore so small a ratio to the length of the solid portion. Considering the existence of the Great Reef running parallel to the coast-line, it would appear, from what had taken place, that a shallow breakwater built upon this reef and connected with the shore by an open viaduct, would have been the true solution of the problem of Cearà. Mr. Voisin's remarks with regard to Boulogne and the data accompanying them were of great value. In reference to Mr. Wheeler's remarks, it was obvious from Mr. Bent's statement as to Cearà that not only did the drift pass directly through the viaduct, but it also passed round the end of the solid work. The two advancing waves of deposit left between them the pool shown in Fig. 22, Plate 4.