## Discussion.

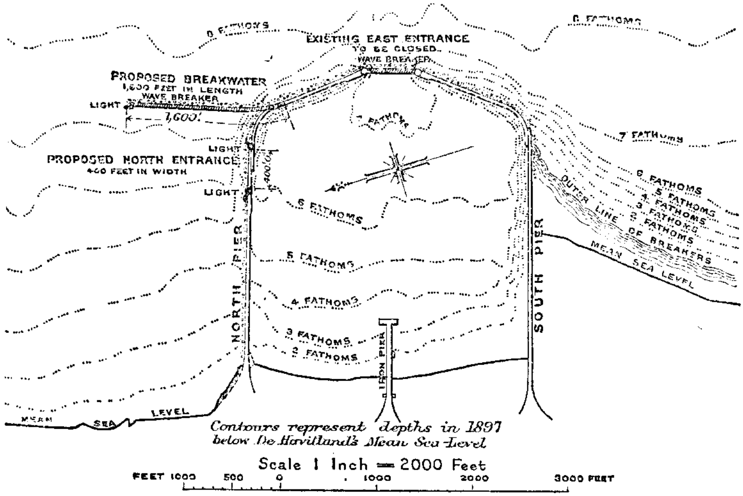
The Chairman. The CHAIRMAN moved a vote of thanks to the Author for his Paper.

The Author. The AUTHOR suggested two points in particular which he thought might be discussed with advantage. It would be interesting to have, first, an opinion, from the nautical standpoint, of the value of harbours of refuge projected into the open sea, and unsheltered from the wind by high lands abutting upon them; and, secondly, an authoritative opinion as to the area of water which ought to be provided for vessels of the maximum draught—battleships, for instance—riding at anchor in partly-sheltered waters.

Mr. Matthews. Mr. WM. MATTHEWS (of Westminster) pointed out that *Figs. 3–20* represented theoretically what might be expected to occur under the conditions indicated in the Paper. In looking at such questions it was important to take into account the particular physical conditions of each case. For instance, wave-force was the most effective influence in the movement of sand on beaches and in the vicinity of works; and at Dover, where the works had been going on for several years, the highest recorded wave measured about 15 feet from crest to trough. There might some day be an abnormal wave; but hitherto no wave of greater height than that had been met with. On the Tyne, however, where the work in connection with the North Pier had been in progress for about 5 years, the resident engineer had reported that he had measured waves of 35 feet and 40 feet from crest to trough; and Mr. Wm. Shield (of Westminster), had measured similar waves at Peterhead. The difference of the wave-force in those cases must materially influence the accumulations of sand in the vicinity of the works, and also the general configuration of the sandbanks under water. With regard to the currents and range of tide, at Colombo, where there was a considerable quantity of sand south of the harbour, the range of the spring-tide was 2 feet, and, as might be expected, there was very little current action. At Dover the range of tide was 18 feet 9 inches, and it was necessary to contend with currents of 4 knots per hour. With practically no current in the one case, and a current of 4 knots per hour in the other, there must be a considerable difference in the action of waves in the vicinity of the respective works. Striking instances of the effect of the comparative volume of tidal water were afforded on the east coast, at Yarmouth and at Lowestoft. Both those ports were subject to the same wave-stroke and the same travel of beach; but there was a considerable difference in the volume of the tidal compartment and in the freshwater discharge. At Yarmouth there was a magnificent backwater, with tributaries running into it, which caused an immense discharge of tidal and fresh water—more than sufficient to keep open the harbour without dredging: in fact, during the 30 years he had known the place, the entrance to the harbour and its approaches had not been shallowing, but had been deepening, and there was a very active travel of sand. At Lowestoft, a few miles away, the harbour was kept open with difficulty, by almost continuous dredging; and this was due solely to the fact that the volume of tidal water was comparatively small. Wave-disturbances, current-velocities, and the volume of tidal water, were three very important influences governing the movement of sand; and they must be carefully taken into account before any opinion could be expressed as to what would take place at any particular point. The Author was quite right in saying that as embanking and reclamation proceeded, the channel shrank in depth; and all encroachment on the tidal compartment should in every case be jealously watched, and wherever possible ought to be prohibited. It was also true that, as the Author said, the whole art of conserving working-depths in and at the mouth of sand-threatened harbours lay in continual dredging. In illustration of this the cases of East London on the South African coast, and Durban on the coast of Natal, might be cited; they were probably two of the worst bar-harbours in the world, owing to the immense quantity of sand in motion. In connection with the development and improvement of their entrances, considerable expenditure had been incurred in carrying out internal training-works, and in the construction of moles. The moles and training-works had been effective to some extent, but both ports were kept open almost entirely by pump-dredging. At East London, when Sir John Coode first commenced work there, in 1877, the depth in the entrance was only 5 feet, and the rise of tide about 5 feet. Now the entrance had been improved to such an extent that vessels of 5,000 tons regularly entered and left the port. That result had been achieved mainly by pump-dredging, and it was the introduction of pump-dredging in 1886 that had rendered such improvement possible. Bucket-dredgers could not have worked in such a situation, in consequence of the wave-disturbance. The capacity of the first pump-dredger used Mr. Matthews.

Mr. Matthews. at East London had been 450 tons, of the second 600 tons, of the third 1,000 tons; while recently a new dredger, of 2,000 tons capacity, had been sent out. That showed what a development had taken place since 1886 in the size of pump-dredgers. A large pump-dredger could work when it would not be possible to use a small dredger, in consequence of sea action. Further, much more work could be got out of it than out of a small dredger—an important point when the weather was favourable only for limited periods. With regard to Madras, he had had opportunities of obtaining information as to the situation there, because he had had to work up, under his old chief, the late Sir John Coode, the investigations of two Committees, and he had been

*Fig. 32.*




a member of a Committee himself, with Sir Charles Hartley and Sir George Nares, in 1902. The present position of affairs at Madras rather differed from what was stated in the Paper; the Author's information was evidently based on what occurred in 1890, while Mr. Matthews's information was almost up to date. In 1902, the sand had gathered outside the knuckle of the South Pier, had passed along the outer wall of that pier until the entrance was reached, and had shallowed the entrance to the extent of 5 feet. In consequence of that action, and of the exposure of the harbour to cyclones, which rendered the harbour incapable of being used by shipping on such occasions, the harbour-authorities at Madras, in conjunction with the chief engineer of the

Presidency, had proposed to close the existing sea entrance, to prolong the arm somewhat as shown in *Fig. 24*, but making the protecting arm 1,600 feet in length, so that it would be longer than shown in the diagram, and to leave an opening 400 feet in width further down (*Fig. 32*). The Committee had generally endorsed that proposal, and their idea in recommending the carrying out of those works had been that the sand would travel along the back of the new work. This it would do shortly, as soon as the entrance was finished: some of it would pass northward, and resume its normal travel along the northern foreshore; but a portion would be lodged as a spit under the lee of the new east breakwater, where it could readily be dealt with by means of a pump-dredger working in shelter. There was no doubt that plan was quite feasible. Figures in his possession showed that 550,000 tons of sand would have to be dealt with annually; and that quantity had really been the foundation of the whole investigation with regard to a remedy. If not more than 550,000 tons of sand passed along the back of that work, and a portion of it went forward, then it would be necessary only to deal with the balance by dredging under the lee of the breakwater, which could easily be done by a modern pump-dredger. Mr. Matthews.

Mr. J. C. HAWKSHAW, Past-President, mentioned that in 1874 his father, the late Sir John Hawkshaw, Past-President Inst. C.E., had personally inspected and reported on the principal harbours of the coast of Brazil, from Maranhão in the north to Porto Alegre in the south—among them the port of Cearà. The work carried out at Cearà as shown in Fig. 22, Plate 4, appeared to be almost identical with the plan which had been given in Sir John Hawkshaw's report, and therefore he wished to place it on record that his father's connection with Cearà had ended with his report. He had not been consulted about the work carried out there, and had had nothing to do with the works described in the Paper. On a coast subject to variable currents and drifting sand, it must always be doubtful what the effect of any proposed plan would be; and the best-considered design might require modification in execution. The responsibility for making the necessary alterations rested with those who carried out the plan, and they could not be avoided by following the plan of another engineer. He felt sure that his father, if he had had the carrying out of that work, would have modified his design when the effect of the work on the travel of the sand became apparent. Mr. Hawkshaw.

Mr. C. B. CASE could not agree with the Author that if the wind was dead on-shore steep slopes of shingle and flats of sand Mr. Case.

Mr. Case. resulted, whereas if the wind struck the coast obliquely the shingle was dragged down to a long slope. The average angle of repose of a yielding beach depended mainly on the bulk, shape, and specific gravity of the particles of which it was composed; but that angle necessarily varied in harmony with changes in the action of the waves and currents. Those changes might be communicated from a distance, but they were more pronounced when arising from an alteration in the direction of the local gales, which raised the heaviest seas. An on-shore gale, therefore, affected the beach quite differently from one that struck the coast obliquely; but the difference was not that suggested by the Author. It was the on-shore gale that caused the beach to be dragged down to a longer slope; and this for several reasons. In the first place, the more the wind blew behind the waves, the more they skimmed the surface of the beach as they plunged, and the farther they projected their wash upward. Moreover, the wash flowed directly up the beach instead of in a slanting direction, as it did with oblique waves, and its upward progress was further assisted by the wind. The result was that the fetch of the wash attained its maximum when the wind was dead on shore, and its planing-action was consequently then most developed. Further, the wind drifted the surface-water towards the land, and there banked it up —especially between converging coasts—until an undercurrent was forced out seaward, which tended to flatten the beach still more. Waves that struck the coast obliquely produced a travel of material coastways; but the movement between sea and land was proportionally diminished. He did not follow the Author's statement that ground-swell and tides were much alike in their action, both producing terracing. He was under the impression that the production of terraces had nothing to do with the presence or absence of ground-swell, though of course their production was favoured by changes in the level of the tide. Any fair-sized wave would throw up a "full" of material, the position of which marked the highest level attained by the wash; terraces were simply a series of such "fulls," arranged in different positions corresponding to changes in the form of the beach, the height of the tide, and the action of the wash. A plentiful accumulation of shingle in a tideless sea would usually exhibit a "full," marking the limit of the wash during the heaviest storms. Below that there would be another "full," conforming to the wash for the time being; and there might be one or two intermediate "fulls." The effect on the same beach of the action of tides, would be to increase the number of "fulls," in consequence of the variation in the level of the waves at the time of high tides. *Fig. 8* was somewhat puzzling. What was the reflex action referred to, and why was there no accumulation around the ends of the breakwaters, the supports of which must to a certain extent retard the travel of material? The waves, running more or less alongside the breakwaters, were travelling towards the beach. How were they reflected from an obstruction against which they were not impinging? There could be no mutual reflection between the breakwaters and the beach, for there the energy of the waves was completely converted. With the balance of littoral forces which the Author had assumed, Mr. Case would have expected accumulation around the open ends of both breakwaters. The accumulations within the harbour would merge into each other more or less, but in any case they would exhibit concavity rather than convexity opposite the entrance of the harbour. It seemed that in the majority of harbours the deposition of current-borne sediment was chiefly effected within a comparatively small area dominated by the eddies just inside the heads of the breakwaters. A shoal was there formed, which was prevented by the action of the waves from rising above a certain level. Thus, material was almost continually falling on the shoal, and was spread abroad by the waves until it gradually settled in various parts of the harbour where, in the absence of scour from behind, the water was sufficiently quiet to afford it permanent refuge. That suggested the possibility of controlling the material deposited in the shoals, so as to prevent it from spreading over the harbour. What, for example, would be the effect of connecting the two breakwaters by a submerged vertical barrier, springing from them immediately behind the shoal-area, and bulging seaward, so as to project beyond the harbour-entrance? Presumably, without coming too near the surface, a barrier of that kind could be erected of such a height that the silt banking up in front of it would, before rising to the level of its crest, tail off so far seaward as to project well beyond the harbour, where it would be sufficiently exposed for its further growth to be restrained by natural forces. Mr. Case.

Mr. W. H. Hunter thought it would be agreed that the Paper was valuable in the sense that it would be likely to lead to thoughtful consideration of the subject. Had the principles laid down by the Author been understood and acted upon, a great deal of trouble would have been avoided, and expenditure saved, in connection with the attempt to form a harbour on the Caribbean coast, for the Nicaragua Canal. There, all the conditions described by Mr. Hunter.

Mr. Hunter. the Author obtained, in spite of which an abortive attempt had been made to construct a breakwater. A short length of breakwater had been run out, with the inevitable result that the sandbanks had overtaken it. Attempts had then been made to prolong the breakwater, but as fast as it was constructed the banks of sand had projected still farther; and so matters would have gone on indefinitely had not operations been wisely brought to an end. He ventured to suggest that the opening sentences of the Paper contained a contradiction of terms. The Author stated that on a tidal foreshore when the balance of the littoral forces was disturbed by solid works, especially when moving sand was present—that was the key-note of the Paper—an alteration of the contours of depth followed as a natural consequence. The presence of moving sand demonstrated that no balance of forces existed. Where there was equilibrium there was no movement: where there was movement there was lack of equilibrium. The forces which prevailed—the forces which the Author called "littoral"—were effects of the operation of two great laws, one, the law of gravitation, acting directly upon the particles of sand and shingle and also producing tidal and atmospheric action; the other, the law of centrifugal force, causing wind as the earth revolved upon its axis. That criticism, however, did not affect the conclusions at which the Author had arrived; it indeed rather added force to those conclusions.

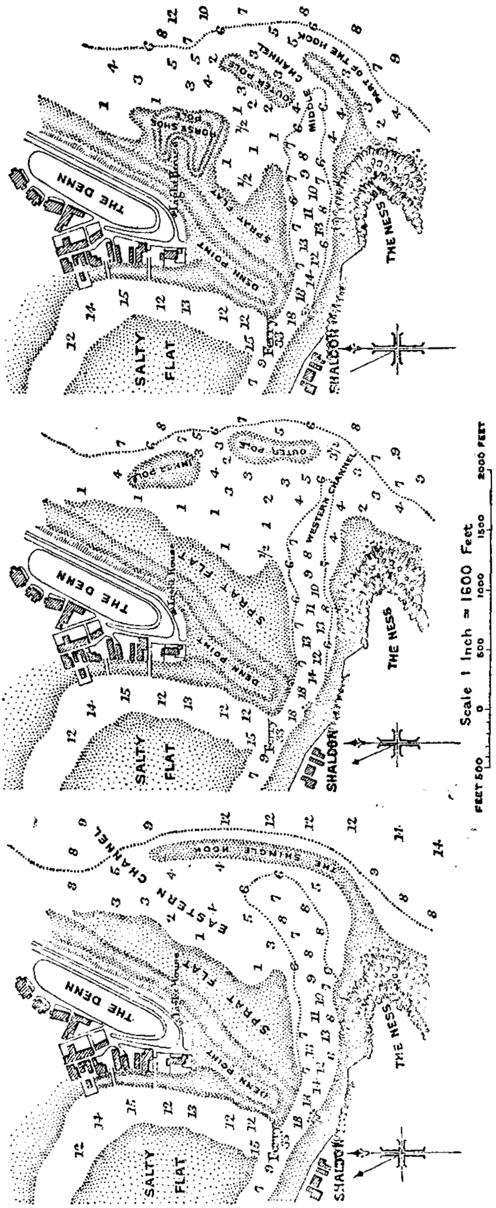
Commander Frederick. Commander G. C. Frederick, R.N., observed that there were doubtless cases in which there must be a conflict of opinion as to the best form of harbour-entrance from engineering and navigational points of view; and often the result had to be a compromise. From an engineering point of view a harbour might be perfect, but if it could not be used for navigation it would be useless. One of the most important questions for discussion was the direction of the entrance, and Madras Harbour was a case in point. From a navigational point of view it had been desired that the entrance should be as depicted in *Fig. 23*, namely, straight out to sea. At the entrance to the Tyne there were two piers running straight out to sea, and vessels could enter safely under all conditions of wind and weather. But a harbour-entrance of that description was not suitable at Madras, because it caused the harbour to silt up; and other forms had had to be designed, notably that described by Mr. Matthews (*Fig. 32*). Even from a navigational point of view that seemed to be a sound plan, because ships could run under the lee and enter with greater ease than they would with such an entrance as was shown in *Fig. 23*.

With long narrow ships, there was considerable difficulty in entering a harbour where the tidal current set directly across the entrance. If the entrance was narrow, as soon as the vessel's bows were inside, the fore end of the ship was in still water, while the after end was exposed to the full force of the current; and she might be twisted rapidly out of her course, with considerable danger. Where it was possible to enter under the lee, as in *Fig. 24*, it would be safer to do so. The space required by battleships depended upon circumstances. In a narrow harbour where ships were exposed to strong winds, they might want a large amount of cable out if they used their own anchors and thus occupied considerable space, even allowing for smooth water. But in an enclosed harbour with moorings laid down, as was being done at Dover, the ships could swing at their moorings, and less space would be required. Large harbours in which ships could veer their cables in bad weather were advantageous; but in confined harbours, like Malta, where there was very little room to spare, it was more a question of the strength of the moorings than of the space in the harbour. Commander Frederick.

Mr. J. C. INGLIS remarked that any attempt to formulate general principles in connection with harbour-engineering must be interesting to members of the Institution. At the same time, Mr. Matthews had given a useful word of caution in saying that every case must be dealt with on its merits. *Fig. 14* reminded him of the conditions of the harbour of Teignmouth, which had been left entirely to itself on account of want of funds. He had examined the harbour and the reports made on it by several eminent engineers, from 1821 onward, and had noticed a curious cyclical change in the conditions. The configuration of the harbour was similar to that shown in *Fig. 14*, as would be seen from *Figs. 33* (p. 240), which represented three successive stages in the cyclical change. There was an abundant discharge of fresh water, and also a strong tidal discharge. The prevailing drift was coastways, and the preponderating wind from the south-west. With a strong outfall of tidal and fresh water, the conflict of currents had tended to a deposition at the Hook, which had extended to 700 yards; and periodically the depth of water over the bar had gradually diminished from what might be said to be its normal depth. Sometimes suddenly, as the result of storms, at other times gradually, the bar or natural breakwater formed by the Hook had extended, deflecting the outfall to the north. This deflected current, as *Figs. 33* showed, had gradually deposited material at the outlet of the extended Hook. The process had gone on until the entrance to the Mr. Inglis.

Mr. Inglis.

Figs. 33.




PLANS SHOWING MOVEMENTS OF TEIGNMOUTH BAR.

harbour was seriously blocked, and then, generally suddenly, the Hook had been broken through, and a direct entrance obtained to the harbour. Captain Spratt, a careful observer, noted in 1853 that the complete cycle of these changes had taken place in 7 years; but even this period depended upon prevailing winds and periods of storm.[1] A very interesting report on this harbour, made by Sir John Rennie in the year 1838, was well worth quoting, as showing the result of his investigations in that year, and as explaining the above phenomena, which then caused the Commissioners to apply to him for advice. Describing the history and configuration of Teignmouth Estuary Sir John Rennie said:— Mr. Inglis.

"The southernmost point of the Den had been considerably reduced in length and height, and was beaten down by the violence of the waves, so that the waters of the Teign, instead of issuing in one combined and uniform mass, so as to enable them to act in the most effective manner in resisting the opposite and more powerful action of the sea and wind from without, were dispersed over a large area, and thus their force was considerably diminished, and became incapable of maintaining a deep and direct channel to seaward, and were necessarily compelled to run parallel to the shore until they had acquired sufficient force to discharge themselves, and in this manner the bar may be said to be in a continual state of change. When the easterly winds prevail then it extends a considerable distance along the shore from the Ness in front of the Den; when the westerly winds prevail, then the Teign, being protected at the mouth, naturally takes the most direct course to seaward; the southern part of the Den accumulates both in length and height, and forms, as it were, a pier or breakwater to quiet the waters issuing from the river in the most beneficial direction, and the bar is then considered to be in the best state, the entrance being close to the Ness, so that depending upon either of the above causes the bar and entrance is confined to a range of about ¾ of a mile."

This showed that sandbanks did not always behave in the manner suggested by *Fig. 14*. They had a way of demonstrating that there was no equilibrium in sea-coast matters. Teignmouth Harbour was not large; but he thought it was well worthy of closer study, as an example of what happened when a harbour with ample scour was left entirely to itself. Cearà Harbour seemed to bear a striking resemblance to Rosslare Harbour, with which he had something to do. There the principle of an open viaduct running out to a solid breakwater, placed exactly as shown in Fig. 22, had been entirely successful. That was another example which supported Mr. Matthews's view that each case must be judged on its merits.

[1] T. Spratt, "An Investigation of the Movements of Teignmouth Bar." London, 1856.

Dr. Owens. Dr. J. S. OWENS considered that a current flowing in simple stream-line motion, which rarely occurred, had no power either to lift material or to hold it in suspension. Therefore it was necessary to look to eddies and irregularities in the motion as the means of keeping material in suspension. Consequently, if a current were flowing whose velocity remained the same, but which at one place traversed broken water, and in another passed into sheltered water, it would seem that the current should pick up material in the disturbed part and deposit it in the sheltered part. The bearing of that conclusion upon a harbour affording free ingress and egress for currents was obvious, as the part sheltered by the harbour would allow deposition. The question arose, was it possible to utilize that principle by producing eddies artificially and causing a picking-up of material where it was desired to produce scour or erosion. He knew of cases in which depositing rocks and loose boulders on the foreshore, with a view to protect the beach, had produced the reverse effect, presumably because the eddies had caused the material to be picked up. Again, it would seem to be a logical inference that, in order to prevent erosion, the bottom should be kept as smooth as possible—more especially in the shallow water on the foreshore—and all projections and abrupt changes of contour should be avoided. The principle appeared also to have a bearing upon the spacing of groynes. It would be possible to space groynes so close together that any current passing over them would be sufficiently disturbed to prevent the deposition of material. An interesting case similar to that of Teignmouth Harbour was the outfall of a small river at Heacham, on the coast of Norfolk. At one time the river, which was not of much commercial importance, had its outfall at right angles to the line of coast, while the present outfall was nearly 2 miles farther south; and the river was separated from the sea by a narrow sandspit not more than 40 to 50 yards wide, and between 1½ mile and 2 miles long. The cause of that was obviously the drifting of the material from the north. The preponderance of the tidal and littoral forces producing drift from the north over the force of the outflow from the small river, was so great that the spit had gradually grown southward, and had diverted the course of the river. The production of the spit, however, had increased the extent of the tidal basin, and the much larger outfall which consequently took place at every tide had restored the balance, so that the spit was no longer growing, and a great deal of erosion round the point of it was taking place.

Mr. F. N. THOROWGOOD had been engaged on the Madras Harbour works between May, 1876, and September, 1888, and he was glad to have an opportunity of making a few remarks, chiefly on the movement of sand and the difficulties to which it had given rise in the construction of the harbour. The sand that obstructed the Madras Harbour was almost entirely wave-borne, although those who criticised the harbour constantly talked of the sand as being borne by the currents. Many years' observation had shown him that very little sand was borne by the currents, and that nearly all of it was thrown up by the waves. The rapidity of deposition, and the enormous quantity thrown up during the south-west monsoon, were almost incredible. The following was a short account of the first Madras harbour-works:—When he arrived at Madras early in 1876 an endeavour was being made to start one of the arms by tipping rubble in order to advance the concrete block-work. The tipping began with great energy at the beginning of the south-west monsoon, and he found that, instead of getting to the place to start the block-work, the difficulty was to get to the water at all, the sand advancing so rapidly that the work was always in the dry. An enormous quantity of stone was brought down, four trains per day each carrying 320 tons of it. Eventually, when the sand had reached a certain height, there came a very high surf which knocked the surf-bank to pieces. He instantly began to set concrete blocks on the top of the ruined bank, and then the interval between the monsoons occurred, and the sand did not accumulate further. By that time the people of Madras had become alarmed, thinking that the sand would soon get higher up, and that eventually, instead of a harbour, there would be a great spit of sand. The Government requested Mr. Parkes to see whether the advance of sand was not more rapid than he had anticipated. The small groynes which had been put up by the Government along the coast on the north allowed much sand to pass them; and Mr. Parkes had to qualify his original estimate that it would be 160 years before sand would begin to turn the corner at the bend of the south pier. He had no record of Mr. Parkes's modified estimate, but he thought it was about 90 years, so that the matter would give no trouble to the present generation. The object was to run out the south pier so quickly as to anticipate the sand before it got inside with the south-west monsoon. Fortunately that was done, and apparently all that remained was the sand permanently imprisoned between the two piers. The work progressed to a certain point, and then arose another trouble with the sand, which he had referred to in

Mr. Thorowgood.

Mr. Thorowgood. the Institution 22 years ago.[1] When the concrete block-work had reached what was then the 4-fathom line, and was now 2 fathoms, the whole of the rubble base was one day covered 8 feet deep by very fine sand. He tried all sorts of plans to get through it, and finally by sinking an iron caisson in front of the blocks, excavating the sand with a kind of dredger, and setting the blocks on the top of the rubble inside the caisson, some slight progress was made, until one day there came a cyclone which disturbed the whole water of the Bay of Bengal, and swept away all the sand and the caisson, but did not disturb any blocks. After that, there was no more trouble with sand in the foundation, but in the following year the same thing happened at the corresponding point on the south pier. He pushed through it in the same way, and there was no more trouble there. He tried experiments by putting in some iron tanks at 4 fathoms, 6 fathoms, and 7½ fathoms. They were about 3 feet 6 inches cube, with a hole in the top. They were very carefully set, by observations, on the sea-bottom, in a line with the pier, and were periodically examined by a diver; and there was always found underneath the hole a small heap of fine sand, which showed that some sand was coming in from the Bay of Bengal, and apparently also coming in towards the harbour. That, however, was quite different from the sand which kept heaping up against the south pier. The original design of the harbour had the arms at right angles to the main piers, and the entrance 450 feet wide; but as the work went on the Marine Department thought there would be a better entrance if they were sloped, and therefore the arms were sloped (*Fig. 23*) and the width of the entrance was increased to 550 feet. The work went on well until 1881, and both piers were got out to the two pier-heads; then the public considered the harbour finished, and many sailing ships used to come in and anchor. He had seen as many as twenty-two native craft anchored, and a large full-rigged ship there also. In the meantime he was putting down screw-moorings for steamers, according to the orders he had received, and also levelling up and making a kind of quay-wall. But on the 12th November, 1881, a terrible cyclone occurred. He had been on the Tyne Harbour for a long time, and had seen much larger waves at the mouth of the Tyne than were seen in that cyclone, which knocked over the ends of the breakwaters of the Madras Harbour; but he had never in his life seen such a

[1] Minutes of Proceedings Inst. C.E., vol. lxx. p. 36.

Mr. Thorowgood.

confused sea. There was no lee side; the waves came from every direction, poured over both breakwaters, and, rushing through the entrance, knocked over into the harbour large portions of both piers, leaving the bottom blocks. The damage done by this cyclone was almost as interesting as it was disastrous. From the end of the curved work outward, in both piers, the blocks (weighing 27 tons each) were knocked over into the harbour; but along the curved work (also on both piers) the eddy of the confused seas undermined the walls, and all the blocks fell over outward, namely towards the attacking waves. This was an extremely important point to notice. The putting-down of the screw-moorings was done by having the screwing-apparatus between two hopper-barges fastened together, which deposited the rubble base. The harbour was practically finished, and the entrance was of its final width; yet the whole screwing-apparatus was nearly carried away by the send of the waves inside the harbour. According to formula a 10-foot wave should have become a 2-foot wave by the time it reached the full width between the piers; but as a matter of fact, the wave was 3 feet high there, and that wave, travelling onward and getting into shallow water, caused a good deal of trouble and made it very difficult to put down moorings. If there was much swell outside, the water inside was not smooth. Such was briefly the history of the first harbour constituted at Madras. One of the difficulties had been to prevent the tremendous erosion which had occurred on the shore about $3\frac{1}{2}$ miles north of Madras. Villages, almost towns, and sacred burial places of natives had been washed away, and the only course had been for the Government to buy the land and let it be washed away. Every sort of protection had been put down. Groynes had been useless, because there had been nothing to catch; the harbour had caught everything. That had added a great deal to the worry and trouble of carrying out the work. By the courtesy of Sir Alexander Rendel he had recently seen the latest soundings at Madras, at the entrance. Whereas, according to the last survey made by him, in 1888, the contour-line at the site of the entrance was $7\frac{3}{4}$ fathoms, it was now only 6 fathoms. Whether the sand which had filled up the entrance was what had got round the end he was not quite sure, because here another factor came into the question. In the Bay of Bengal there was an almost ceaseless surf. The Home Committee which reported upon the Madras Harbour in January, 1883, recommended, among other things, the raising of the two breakwaters. Before that was done, in anything like a sea the water used to pour over the breakwaters

Mr. Thorowgood. in cascades, so that it was extremely dangerous to go along them, and many men were washed away and drowned. The result of that constant falling-over of water into the small enclosure was to make the level of the water inside much higher than that of the water outside, and there was always a strong outward current at the entrance. He believed it was this action which had kept the entrance about the same depth as at the beginning; and Sir Alexander Rendel had told him that the two breakwaters had been raised 6 feet, and now nothing like so much water came in. The water inside was consequently not much higher than the water outside, and there was less scour at the entrance. He could not help thinking that the enormous silting at the entrance was as much due to that fact as to the advance of the wave-borne sand. Every one had been disappointed that when the first harbour was finished up to the entrance, the result with regard to smoothness of the water inside was not as good as had been hoped for. In 1882 he came home on 12 months' sick-leave, and in 1883 a Committee, consisting of Sir John Coode, Sir John Hawkshaw, and Sir George Gabriel Stokes, considered the question of restoring the damaged part of the harbour: they recommended raising the breakwaters and strengthening them with random blocks outside, but they did not recommend altering the entrance. In 1883 he was in Madras again and found that Lieutenant-General Sir Richard (then Colonel) Sankey, was very anxious to alter the entrance so as to prevent the swell from coming in. Later on, Mr. Thorowgood sat on the Committee which proposed a design similar to that shown in *Fig. 24*, involving the closing of the eastern entrance and the formation of an entrance on the north side. No sand came from the north and there was no fear of silting there. He did not think that plan was good for navigation, and he would not like to be a skipper bringing in a ship with an easterly swell; it would, however, have given smooth water. But it was not done, as his orders were to go on rebuilding according to the plans. In the meantime the works had been taken from the Government and put under a Local Board, and they appealed home and said they must have the eastern entrance closed. Another Committee sat, consisting of Sir Nowell Salmon, Sir George Nares, and Sir John Coode. Their report was in favour of closing the eastern entrance if the sand appeared to advance more rapidly, not, however, of closing it at once, but simply of stopping the north pier in its rebuilding, while pressing on with the south pier. Evidently that had not been carried out, because both piers had been gone on with and had been got into the shape

Mr. Thorowgood.

shown in *Fig. 23*, with what result he did not know, except the silting-up of the mouth, which he was inclined to think was largely due to the want of the scouring action which formerly resulted from the sea pouring over the two breakwaters and filling the harbour to a higher level than the water outside. Major-General Thomason, who was very much interested in the matter, was sent by Sir Andrew Clarke to examine the movement of sand. His investigations were elaborate and interesting, and he evolved out of them the design of the harbour shown in *Fig. 25;* but how on that plan goods were to be got from the ship to the shore Mr. Thorowgood did not know. No doubt a sand-pump dredger would, as Mr. Matthews had stated, be alright under the lee of the breakwater, but it would have a bad time if there was any swell coming in. A sand-pump dredger was on its way out to Madras, to dredge the opening, in the hope that things might be improved thereby.

Mr. Dobson.

Mr. J. M. Dobson stated that in 1901 the Madras Railway Company were approached by the Madras Chamber of Commerce with reference to the various improvements proposed for the harbour, with the idea of obtaining their support; and, in consequence, Colonel Gardiner, the Chairman of the Company, called upon Messrs. Hawkshaw and Dobson to report upon the whole question, which they did in November of the same year. The subject was by no means a new one to them, because in 1883 the late Sir John Hawkshaw had reported, jointly with Sir John Coode and Sir George Gabriel Stokes, as to the best method of restoring the breakwaters which had been partly destroyed by the cyclone of 1881. No doubt Mr. Parkes had considered, from the information at his disposal in regard to the travel of sand, that the accumulation would be very small, and, in consequence, started the north breakwater before the south, a circumstance which had always been difficult to understand. It was stated in the Paper that the south breakwater was not started until 2 years' work had been carried out at the north breakwater, but he thought the Author was misinformed on this point, because in a valuable report[1] made by Sir Guilford Molesworth in 1882 it was stated that the north breakwater was started on the 17th December, 1876, and the south breakwater on the 19th November, 1877, an interval of only 11 months. Yet in this short period, according to Sir Guilford Molesworth, a very large accumulation of sand took place in the harbour itself, owing to the north breakwater

[1] "Papers connected with the Construction of the Madras Harbour," p. 110.

Mr. Dobson. having been started before the south. From Mr. Thorowgood's observations it appeared that the sand at Madras was wave-borne, and that an in-and-out movement of sand outside the line of surf took place during the south-west monsoon in $2\frac{1}{2}$ to 3 fathoms of water; while Sir Andrew Clarke pointed out in 1879 that the wave force was the only scouring force of any practical importance at Madras. Admitting that the sand was wave-borne, and that the current was only 3 miles per hour, but bearing in mind that it ran from south to north for 7 months of the year, he did not think anybody could look at the plan of Madras Harbour which he had put upon the wall (*Fig. 34*) without coming to the conclusion that the 3-mile current had a great deal more to do with the silting-up at Madras than many supposed. On the plan were marked the foreshore in September, 1881, and the foreshore in 1890; and it would be observed that by 1890 the foreshore had come forward no less than 1,250 feet, so that where in 1879 there were 36 feet of water, on the south side, there was now high-water mark. On the south side of the harbour the 8-fathom line had come forward 940 feet, while at the entrance it had only come forward some 500 feet. He thought there would be no difficulty whatever in keeping the harbour open, as well as the entrance, by using a suction-dredger of moderate size; because, taking 5 feet as the depth of silting over the whole area between 1879 and 1890, it meant removing 15,000 cubic yards per month. With a dredger lifting 4,000 cubic yards per day that could be done by working 4 days per month; and even taking Mr. Matthews's figure of 550,000 tons, which was about 458,000 cubic yards, or 38,000 cubic yards per month, the same dredger would deal with that in 10 days. Therefore the question of silting had been largely magnified with regard to Madras Harbour. He agreed generally with the Author's remarks as to silting, but held that special circumstances might alter the application of general principles. In the River Plate he had seen large quantities of sand being carried in shallow water with a 3-mile current. The waters from the Paraná brought an enormous amount of sand, which was carried in suspension along the bottom, passed down the river in front of Buenos Aires, and was dispersed over a large area; and that had gone on, to his knowledge, for 10 years, without diminishing the depth of water in the river to any appreciable extent. But no sooner was a channel cut—no matter how obliquely it was put to the current—or groynes projected, or breakwaters built, than the presence of the sand was immediately felt. The Madras Committee of 1883 suggested in their report that the eastern entrance should be closed and that another entrance should be made as shown in *Fig. 24;* and that report was submitted to Sir John Hawkshaw and his colleagues on the Home Committee, who reported, in March, 1884, that if an entrance were made in the north-east corner, it would be very difficult for vessels to enter or leave the harbour in a cyclone; and he believed that was quite true. They also pointed out that, if a new entrance were formed, there Mr. Dobson.

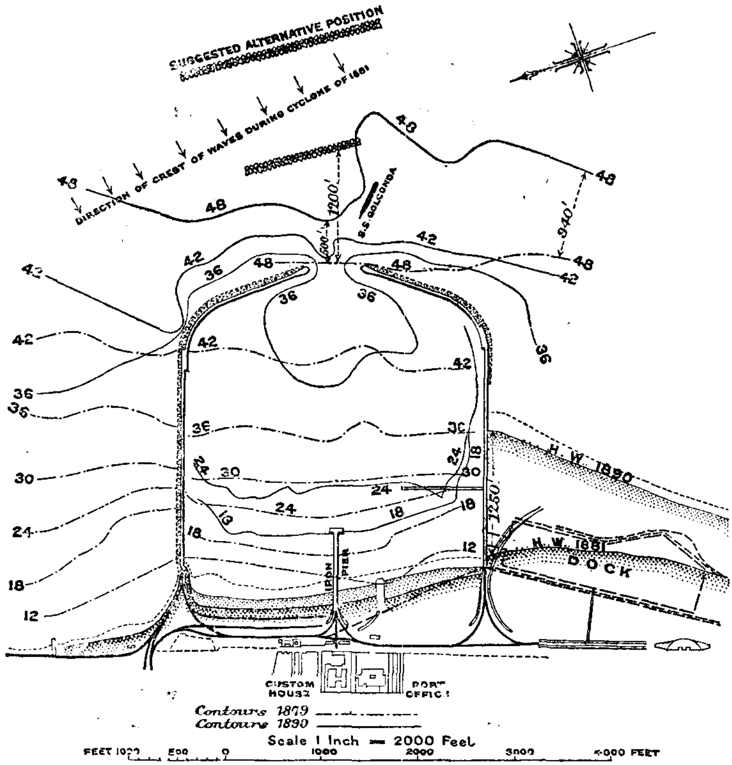


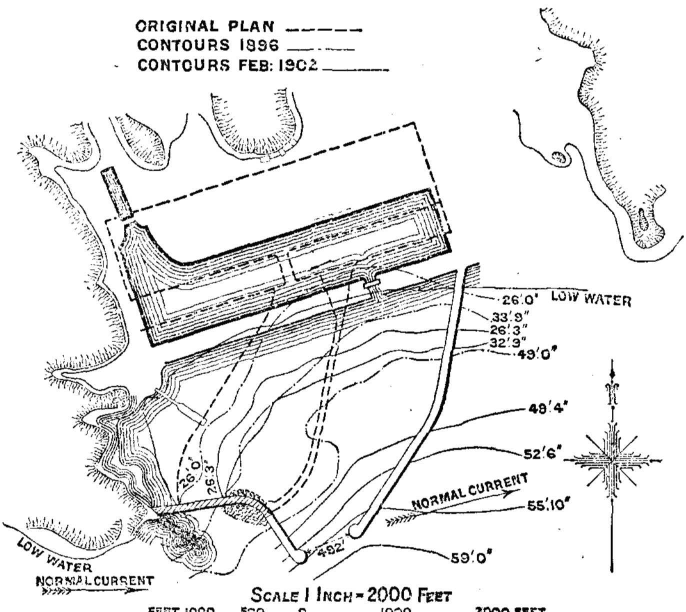

*Fig. 34.*

would be two entrances to the harbour for a time, and that in consequence the water would be much more disturbed; and in conclusion they stated that after having carefully considered the question they could not recommend the construction of the new entrance. As had been said by a well-known authority, to make a harbour secure at the expense of its accessibility appeared to be a worse fault than to make it accessible at the expense of its security; because, as a rule, it

Mr. Dobson. was possible to improve the security of a harbour by internal works. For that reason, and bearing in mind that the waves rolled unceasingly towards the shore, Messrs. Hawkshaw and Dobson had proposed in their report of 1901 that a dock should be made at the south-west corner, constructed so as to meet existing requirements, and so laid out that it could be extended as trade developed; believing that even in the heaviest weather such a dock would give security to vessels, which would be able to lie alongside the quay and discharge their cargoes, using the outside harbour as an outer harbour. They considered that it would be very unwise to make an entrance at the north-east corner, necessitating the prolongation of the north-east arm in a northerly direction; and they were of opinion that if that work were carried out it would lead to precisely what the Author showed in *Fig. 16*, namely, silting between the extended arm and the shore. In their report they had suggested that if, when the dock was completed, it were necessary to render the water in the harbour quieter than at present, this could more easily be done by constructing a protecting breakwater, as shown in *Fig. 34*, laid down at an angle of about 30° with the foreshore. At first the intention had been to place it 1,200 feet from the entrance; but after consultation with nautical men, and bearing in mind the necessity of ships being able to enter in the heaviest weather, in a later report to the Madras Railway Company they had placed it 2,400 feet away, and had made it correspondingly longer. To carry out the works suggested by the report of the Commission of 1902 would be to incur heavy expenditure, and to say the least, it was doubtful what the result would be. Bearing in mind Sir Andrew Clarke's statement, that in British India there were more than 2,000 miles of seaboard from Calcutta to Bombay without a single port where vessels could discharge direct on to the quay, he thought it would be agreed that the time had really come for the Government of India to encourage, in some way, the construction by private enterprise—either by new companies or by the existing railway companies—of docks and breakwaters at such a place as Vizagapatam, acknowledged to be the best site on the east coast for a harbour. Otherwise, if the alteration at Madras turned out as he anticipated, the question of harbour-accommodation in India would become still more serious. Dealing generally with the subject of the Paper, the Author clearly showed in *Figs. 3–20* the evils that arose from interfering with the littoral current, or from forming a bay into which the sand might be carried by eddies set up by the works themselves, or by the ground-swell.

Taking all these difficulties into consideration, he thought the great engineers of the past had been right in fixing the entrances to purely artificial harbours at the furthermost points from the shore; and that the solution of the problem lay in the construction of protection-works still further seaward—always assuming that it was absolutely necessary to exclude the ocean swell from the outer harbour, instead of constructing an inner harbour or dock. He desired to bring before the Institution one other remarkable case, that of Salina Cruz harbour on the Mr Dobson.

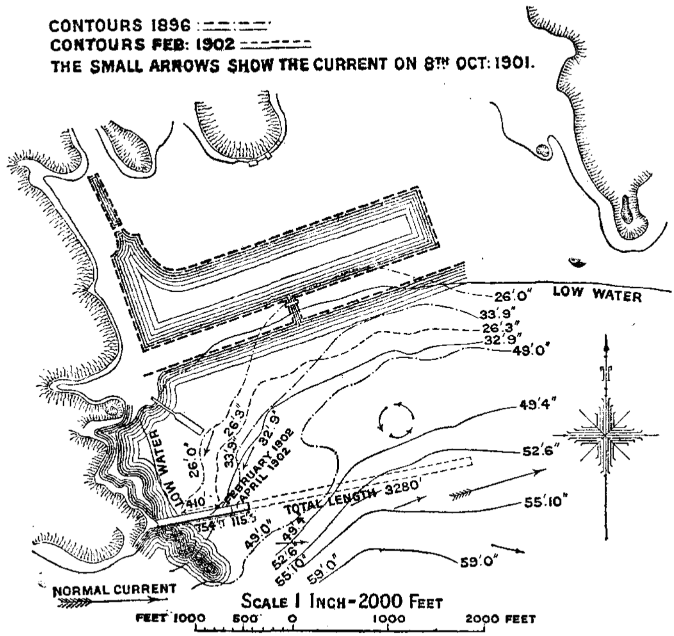
*Fig. 35.*




Pacific coast, which was being constructed for the Mexican Government by Messrs. S. Pearson & Son. In 1896 Messrs. Pearson requested Messrs. Hawkshaw and Hayter to report upon plans for a proposed harbour at that port, and the result was that a scheme was recommended which was shown by the dotted lines in *Fig. 35.* That scheme included an inner dock and two breakwaters, with an entrance parallel to the flow of the littoral current. The current always ran from west to east, and the wind blew for 4 months of the year from the north, and during the remaining 8 months from the south. The proposed

Mr. Dobson. plan was not entirely approved by the Mexican government authorities, who finally decided upon an entirely different position for the entrance to the harbour, with a breakwater extending from the headland on the west and running in an easterly direction, almost parallel to the dock, as shown in *Fig. 36.* The work was commenced in 1890 according to that plan, and the subsequent events had an interesting bearing upon Madras Harbour. As the breakwater was carried out, so the bay which was protected by it gradually silted up, until in February, 1902,

*Fig. 36.*




low-water line immediately behind the breakwater had reached a point where there was originally 26 feet of water. The filling-up alone was naturally sufficient to cause anxiety to any engineer responsible for the scheme; and yet, no doubt, it had never been anticipated, because the impression seemed to have been that the sand, being coarse, was so heavy that it could not be carried by the littoral current. In March and April, 1902, when the breakwater had reached a point 820 feet from its commencement, the bottom of the bay off the end of the breakwater silted up suddenly to the extent of 13 feet. Then the Mexican Government decided to revert to the plan of 1896, and began to curve the breakwater southward. Unfortunately, the Titan which was on the breakwater at that time was thrown over into the sea, owing to an earthquake-wave, and the whole matter was referred to Messrs. Hawkshaw and Dobson. At first it was difficult to understand the sudden silting up of 13 feet off the end of the breakwater; but on further inquiry it was found that that silting was periodical, and took place quite independently of the breakwater. The winds from the south always brought sand into the bay, and the northerly winds took it all out again. That, in his view, was a perfect explanation of the silting, as it was evident the south wind blowing for 8 months considerably lessened the eddy-currents in the bay, so that the sand carried by the strong littoral current running from west to east would be thrown up into the slack water east of the headland; whereas the north wind, as proved by actual observations, increased the power and range of the eddy-current, and this carried the sand again into the influence of the littoral current. In order to revert to the scheme proposed in 1896, and to place the entrance beyond the fluctuating conditions existing within the range of the eddy, an awkward bend was given to the breakwater (*Fig. 35*). This was unavoidable under the circumstances; and it was much easier and cheaper to strengthen the breakwater sufficiently at that corner than to begin it over again in a new direction. The rapid shoaling behind the breakwater during its construction was due to the comparatively slack water caused by interference with the eddy-current, and to the absence of any breakwater on the east to exclude the sand carried by that current. *Mr. Dobson.*

Mr. W. T. Douglass pointed out that in a Note[1] read before Section II. of the Engineering Conference, 1903, he had ventured to express the opinion that, under normal conditions, the travel of the beach was with the flood-tide; while at the same time he did not reject the theory of wave-action, and of the longest fetch bringing in the heaviest waves. The Paper under discussion bore out that theory. *Figs. 12–15*, *18* and *19* showed that the beach was growing in all cases on the side of the prevailing wind and the flood-tide. There was no instance of the beach collecting on the ebb-tide side, except in *Fig. 16*, which showed a lee groyne parallel with the shore. Again, at Madras the accretion, occurring entirely on the south side, was due to the flood-tide. He had Mr. Douglass.

[1] Minutes of Proceedings Inst. C.E. Supplement to vol. cliv. p. 46.

Mr. Douglass. examined the majority of the foreshores and beaches of the British Isles, and had found in all instances that the preponderating travel of the beach was with the flood-tide. Accepting this principle, it was possible to decide in a few minutes what would be the ultimate direction of travel of a beach; whereas, if the records of the Meteorological Office as to prevailing winds were studied, it would probably take a month. The silting-up at Cearà was quite in accordance with what would be expected from the conditions shown by the diagrams. There was an isolated breakwater connected to the shore by a viaduct 750 feet in length. As shown by Fig. 21, Plate 4, the viaduct was built over a harbour-reef. The tendency would be for that reef to act as a groyne, and for silting to take place. This condition obtained on nearly every sandy foreshore, where about low-water line there was a small reef, ledge, or island; and in most cases an isthmus of sand joined the reef or island to the foreshore. A notable instance was Portland, where Portland Island formed the isolated breakwater and the Chesil Beach formed the isthmus. The late Sir John Coode, in his Paper on the Chesil Beach, attributed the collection of beach there to the existence of a shelf of Kimmeridge clay standing 4 feet above the foreshore.[1] In regard to Madras Harbour the general effect that would result from the suggested building-out of a breakwater or protecting arm on the north side of the harbour was shown in *Figs. 7* and *16*. A sheltered area would be created on the lee side where the sand would deposit. Another instance was Gorleston, where, about the year 1873, Sir John Coode recommended the construction of a groyne at right angles to the south pier of the harbour, where encroachments had been going on to a very serious extent, which would probably outflank the harbour. The groyne was built of open pile-work, and effectually prevented further denudation of the foreshore. About 1880 this groyne was reconstructed and made solid; with the result that the whole of the foreshore on the south beach was silted up, and the groynes were covered. During the past 12 months the Corporation of Yarmouth had been compelled to raise their sea-wall in order to get rid of the sand trouble. A similar encroachment of the sea on the lee side of the breakwater had been occurring for many years at Lowestoft, and in 1901 he advised the Corporation to construct a groyne on the south face of the southern harbour-pier and at right angles to it. That groyne had now been completed, with the result that the sand had accumulated on both sides of the groyne to a height of 10 feet and the

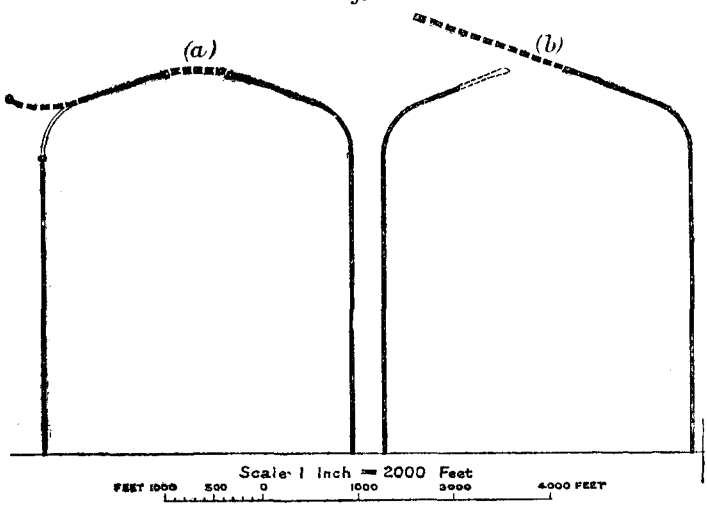
[1] Minutes of Proceedings Inst. C.E., vol. xii. p. 542.

high-water line had already been driven back 150 yards. The groyne was 235 feet in length. His theory of the flood-tide was borne out by every remark in the Paper, with one exception, where he thought the Author, in describing the tide at Littlehampton, was incorrect in stating that there the flood-tide travelled from east to west. It was well known that the flood-tide on the south coast travelled from west to east; though it was true that 2 hours previous to high water the flood-tide at Littlehampton did begin to ebb in-shore and travelled westward for 5 hours, so that there was 7 hours of flood and 5 hours of ebb. With regard to the Author's remarks as to the use of piled structures and their availability for traffic in moderate weather, so far as the landing of goods on the coasts of Great Britain was concerned, there were instances of piers built at Yarmouth, Lowestoft, Southend, Margate, Ramsgate, Brighton, Hastings and Eastbourne, where, even during the summer months, very considerable difficulty was experienced by high-power steamers in landing their passengers; and he thought that if any attempt were made to land cargo from small boats, which were frequently undermanned, great difficulties would arise in taking the cargoes out of the holds of these craft, even with cranes of special design, having long jibs. Further, when these small craft were lightened of their cargoes, they would have great difficulty in clawing off the shore in bad weather. Mr. Douglass.

Sir GUILFORD L. MOLESWORTH, K.C.I.E., Vice-President, remarked that there was one interesting effect of silting which had not been touched upon by the Author, namely, the formation of lagoons. He had seen it often in Ceylon. Where a river debouched at right angles to the foreshore, a sandbank was often formed at one side of the mouth, which was deflected by the flow, parallel to the shore. The sandbank gradually extended parallel to the shore, until a heavier flood-discharge than usual broke through the root end of the bank, and the process was repeated. Some of these lagoons were more than 20 miles in length. With regard to the effect of the movement of water, there were several influences which, combined, often produced different results under apparently almost similar physical conditions. For instance, there was not only the ground-swell, but there were also perhaps monsoon currents, the local current, and the surface waves, acting in different directions. Variations in the relative effects of those elements would produce very different results. As a rule, the ground-swell came broadside on to the foreshore. Having been requested by the Government of India to investigate the causes of the failure of the Madras Sir Guilford Molesworth.

Sir Guilford Molesworth. Harbour, he went there just about the time when the strength of the monsoon had subsided. There was then a large accumulation of sand on the north side, which was probably due to the fact that the north breakwater had been commenced before the south breakwater. The accumulation was now on the south side. The report of the Home Committee (Sir John Hawkshaw, Sir John Coode, and Sir George Gabriel Stokes), recommended the narrowing of the harbour-entrance from 550 feet to 450 feet; but he had calculated that such a reduction would not make a difference of more than 1 foot in the height of waves inside the harbour, 1,500 feet from the entrance. The report of the Madras Committee

*Figs. 37.*




advised an entrance at the northern elbow in lieu of the existing entrance at the east front, and on this point he had reported[1] thus:—

"The 'Madras Committee,' however, has recommended the closing of the present entrance, and opening of a new entrance in the north elbow, this entrance being covered by a projecting break-water curving out from the eastern tangent of this elbow. The entrance to a harbour at right angles to the general direction of the swell is generally considered to be a very disadvantageous arrangement; for when a vessel is entering such a harbour, half protected by the entrance, and half exposed to the action of a heavy wave, it is liable to be swung round, and strike the

[1] "Papers connected with the Construction of the Madras Harbour," pp. 173 and 174.

Sir Guilford Molesworth.

entrance before it can recover itself: this is a contingency to which modern vessels from their extreme length are especially liable. . . . Assuming, however, the feasibility of such an entrance, I am of opinion that the form of break-water proposed for covering this entrance requires some modification. In its proposed form it is open to serious objections, involving, as it does, a re-entering curve. . . The meeting of the confluent waves along the face with those rolling in direct from the sea would set up a very severe action, and the blows on the concave surface would be so severe that nothing in the shape of a break-water could withstand it. . . There is another alternative entrance that might be worthy of consideration as offering shelter to the harbour without the objectionable features of either of the foregoing alternatives. This is shown in . . . [*Fig. 37b*], one of the faces being extended so as to cover the existing entrance, and, by demolishing part of the other face, a sufficient width for a free entrance may be obtained. This would allow an entrance in deep water, and it is doubtful whether it would be more expensive than the plan proposed by the Madras Committee. If there should be a tendency to rapid shoaling to the south, it might be desirable to extend the other face so as to give the entrance to the north instead of to the south; but in this case the extension would have to be rather longer, to give an equal cover to the entrance."

The entrance proposed by the Madras Committee was shown in *Fig. 37* (*a*) and the modification proposed by him in *Fig. 37* (*b*).

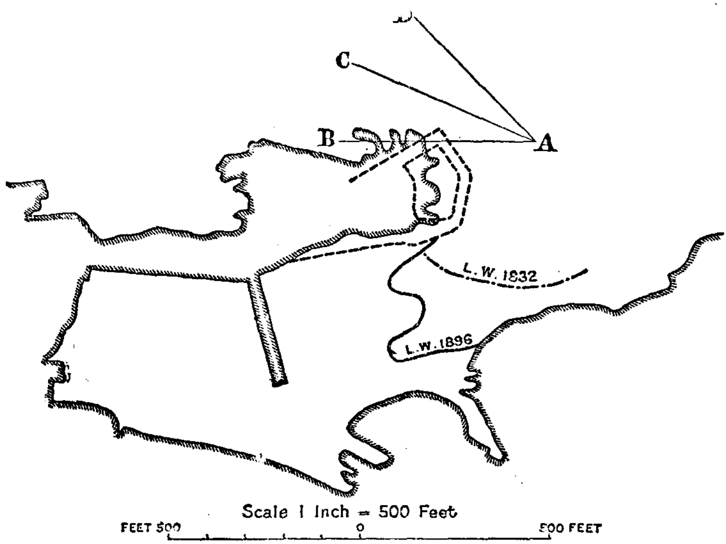
Mr. Pilkington

Mr. WOODFORD PILKINGTON mentioned that he had had a good deal to do with the Cearà harbour-works, having been appointed resident engineer on them in 1885. On arriving at Cearà he had checked the soundings previously made by the staff of Sir John Hawkshaw, and had found them to tally in a remarkable way; showing that there had been absolutely no change in the bottom during the 10 years. He had then pointed out to the contractors that it would be possible to improve on the breakwater, and to prevent the harbour from becoming a land-reclamation scheme instead of a harbour, by turning the breakwater-arm outward in the direction of the wind and wave, instead of turning it into the shore and stopping the current. He had contended that if that alteration were made a thorough scour should be produced throughout the harbour, and silting would be stopped. He had been told, however, by the agent of the contractors, that if the alteration were made no order would be given to proceed with the works for another 3 months, and the contractors would lose their concession; he had therefore given in, though he had been persuaded the place would be silted up. The work accordingly proceeded, and shortly afterwards he relinquished all connection with the works. The cause of the failure of the works was that the breakwater's inner end was curved in towards the shore, thus deflecting the waves caused by the north-east monsoon, and so stopping the inshore equatorial current. It should have been curved out so as to be parallel with the foreshore. Only one-half of the curved

Mr. Pilkington. viaduct was open piling, 350 feet at the inner end of the breakwater being formed of solid concrete; this should have been open viaduct, like the rest. As it was, it formed a deflecting cushion on which the waves impinged and drove inshore. It should have been turned the other way, so as to guide the waves along the outer side of the breakwater; then instead of contracting the channel-way, it would have increased the force of the scour of the wave, acting with instead of against, the equatorial current. He had also brought these views to the notice of the Chairman of the Company before the works had advanced so far as to make it difficult to alter them, but without effect. Sir John Hawkshaw was not to be blamed for the failure of the works, as he had never been consulted as to their execution; but the authority of his great name had prevented timely alterations from taking place when needed.

Mr. Moore. Mr. R. St. George Moore regretted that more had not been heard about home harbours. For instance, he would have liked to hear a little about Portsmouth Harbour, because there was a great deal of interesting information to be obtained from it: moreover, it was near home, and most of the members had had an opportunity of actually seeing it. He had recently been told by the late Superintending Engineer of Portsmouth Dockyard that, in his opinion, the scour had been so successful that it was hoped it would soon be possible to widen the mouth of the harbour. The harbour of Ilfracombe afforded an interesting illustration of the effect of wind and waves in producing scour. In *Fig. 38* the line A B lay east and west, C A was the line of the longest fetch outside the harbour, and D A was the line of the most prevalent of the winds entering the harbour. That wind blew for about 21 days per annum. The dotted lines showed some new work, carried out in 1880, partly solid and partly open. The result of that work was a change in the low-water line of spring tides, between 1832 and 1896, as shown in *Fig. 38*. There was a stream coming out of a culvert, on the south side of the harbour, and passing down the harbour; but it was so small that it would have no effect whatever on the scour. The whole of the scour must therefore have been due to combined wave and wind action. On examining the harbour about 1895, the first point he had had to investigate was why the scour had stopped at that point, and he had found that rock underlay the surface only a few inches. He had then been authorized to dredge away all the rock, so as to see whether further scouring would take place. The works were complete in 1900, and he expected in the coming summer to make a further survey. Christchurch Harbour (*Fig. 39*) was a natural harbour, in that no works had been ever carried out there. In 1662 a Mr. Yallender proposed to canalize the rivers Stour and Avon, using Christchurch Harbour, which was large and land-locked, for the purpose. The peculiarity of the harbour was that in 1811 there was a short direct entrance, whereas by 1870 a spit of land had extended parallel to the shore, diverting the entrance about 1 mile to leeward. By 1896 the spit had diminished as shown in *Fig. 39:* and at present it was extending again. There was a large volume of fresh water coming down the harbour. He had had occasion to gauge the River Avon, and in ordinary winter Mr. Moore.

*Fig. 38.*



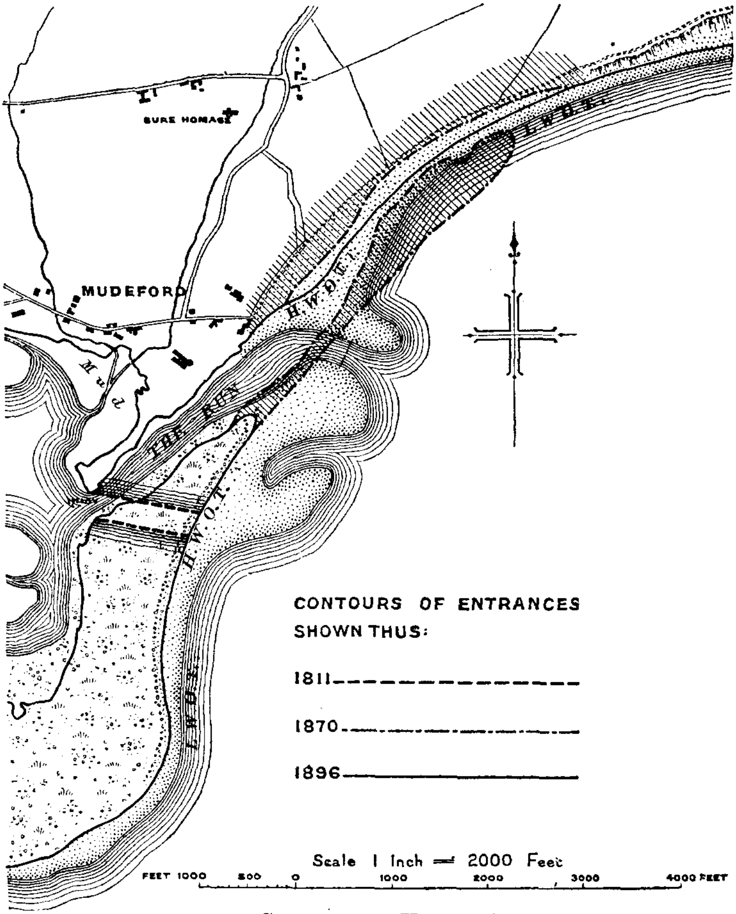

ILFRACOMBE HARBOUR.

weather the flow was 300 to 400 million gallons in 24 hours; while the River Stour had quite an equal amount. If extended, *Fig. 39* would follow somewhat the lines of *Fig. 16* in the Paper, the breakwater being represented by some sunken rocks which diverted the current. The erosion of Hengistbury Head had been about 800 feet since 1840. He would also like to endorse the Author's view that in many instances a piled structure would supply all reasonable trade facilities; as he was of opinion that the utility of properly-designed open piers was much under-estimated. The direction and force of the wind might be

s 2

Mr. Moore. taken as a fair, if not an exact, measure of that utility. For instance, the pier at Swanage was exposed to winds from the north, north-east, east, south-east and south. The winds blowing

*Fig. 39.*




CHRISTCHURCH HARBOUR.

from those quarters, as recorded at the Anvil Point Lighthouse in 1892 and 1893, were as follows:—

| | |
|---|---|
| (1) Calm to gentle breezes . . . . . . . . . | 90 |
| (2) Moderate to fresh breezes . . . . . . . . | 140 |
| (3) Above . . . . . . . . . . . . . . | 22 |
| | 252 |

Mr. Moore.

or 126 days per annum. Off-shore winds blew on 239 days per annum, so that the number of days on which the pier would be available was:—

| | Days. |
|---|---|
| During off-shore winds | 239 |
| ,, calm and gentle breezes | 45 |
| ,, moderate breezes and fresh air | 20 |
| | 304 |

Therefore the pier would be available for about 304 days per annum. Applying the same method to a pier in Gott Bay in the Island of Tiree, statistics taken from the Skerryvore Lighthouse records, showed that the pier would be available for 300 days in a year. At Ilfracombe, from records taken from Bull Point Lighthouse, the pier would be available for 230 days in a year. The following information, supplied by Captain Trenance, the pier-master at the west pier, Brighton, went far to confirm the foregoing deductions:—

| | Season. | Days Missed. |
|---|---|---|
| 1896. | 1 April to 18 October | 25 September and 16 October. |
| 1897. | ,, ,, 12 ,, | 2 September. |
| 1898. | 7 ,, 15 ,, | 30 April, 24 June, 14 October. |
| 1899. | 30 March to 26 ,, | 7 and 4 April, 1 July, 1 October. |
| 1900. | 1 April to 25 ,, | 16 April. |
| 1901. | 4 ,, 31 ,, | Nil. |
| 1902. | 28 March to 31 ,, | Nil. |
| 1903. | 1 April to 24 ,, | 28 July, 15 and 24 August, 5, 6, 11 and 12 October. |

In other words, during the 7 summer months of each of the last 8 years, the days per season on which steamers did not call had been under 1 per cent. In estimating the number of days that a pier would be available, it was necessary to take into consideration its design. In 1888, after considerable difficulties had been experienced in landing passengers from the "Lady Brassey," at the Hastings pier, he had pointed out that landing-stages in unsheltered water should be provided with a number of berths, so arranged that vessels should always approach bow on to the wind and waves. Since that date a number of landing-stages had been built more or less on those lines. He himself had built two. Where it was impossible to get the number of angles, the selected position should be such that the vessels would lie bow on to the prevalent wind. He believed that if the foregoing principles were put into practice, the Author's remarks as to the utility of open piers would be thoroughly justified. Of course there remained always the uncertainty, which was bound to interfere with regular services.

The Author. The AUTHOR, in reply, expressed his thanks for the reception accorded to his Paper. The discussion he thought had in almost every instance emphasized the points he had endeavoured to bring out. In contrasting Yarmouth and Lowestoft, Mr. Matthews had not mentioned the depths at low water at the mouths of those harbours, which it would be valuable to know. The additional information Mr. Matthews and Mr. Thorowgood had given as to Madras, bringing its history up to date, was very interesting. His main contention as to Madras was generally supported by these more recent records. In a Paper[1] by the late Mr. Horace Bell, M. Inst. C.E., entitled "Notes on the Ports and Harbours of Peninsular India," the following reference was made to the Port of Madras:—

"The history of Madras, as a port of any importance, dates no further back than to the days when we selected the place as a trading settlement, and built Fort St. George, in 1639. It was then—and it is scarcely better now—an open roadstead, liable to be swept by storms or hurricanes of intense violence, when every vessel that could venture on the process had to go to sea for safety and a good offing, as indeed is the case at the present day."

The nautical evidence was to the effect that the only gales at Madras were cyclones; and according to the statement of the harbour-master, in cyclones ships had to be sent to sea for safety. In other words, it looked as if in ordinary weather the harbour was not required, while in cyclones it could not be used. He had not visited Madras, and therefore he spoke with great deference; but that was what the observations seemed to imply. Over £500,000 had been expended on the work at Madras, to say nothing of the loss due to the injury to the coast-line by erosion on the lee side. His point with regard to Madras was that the circumstances would have justified a pile-work rather than a solid structure. A piled pier would doubtless have been to some extent intermittent in use; but in the light of the evidence available, it certainly seemed that such a structure would have provided the required facilities. He agreed with Mr. Case that the slope assumed by a beach under different conditions of the wind was largely dependent upon the size and weight of the components of that beach. His remarks had reference to a foreshore with shingle leaving, say, 20 per cent. to 25 per cent. on a $\frac{3}{4}$-inch mesh. With a ground-swell, or a dead-on sea, the shingle was tossed up on to the crest, and the toe of the slope was raked

[1] Journal of the Society of Arts, vol. li., p. 702.

out. As the wave-action increased or slackened, the result was nearly always a series of terraces. A similar result was produced by the variation of the levels of high water, when what might be termed "tidal terracing" resulted. The steeper slope of Dungeness ran a little south of east and north of west, so that the prevailing and heaviest seas struck it almost broadside on. Here the shingle lay at a slope of 2 to 1 in deep water, with a shelf of mud at the foot of the slope. In the late Sir John Coode's Paper on the Chesil Bank was shown [1] a section taken after the storm of the 27th December, 1852. The sea was then practically dead-on, and the slope was cut out so that the profile of the bank was almost exactly parabolic. With regard to Mr. Case's question as to *Fig. 8*, in the centre of the foreshore, between the piers, the forces causing the shingle to oscillate would be checked by reason of the solid portions of the two break-waters. On the flood, for instance, there would be a dead centre where the tidal impulse was checked, owing to slack water. At the same time a reflex action would be set up by the tidal force striking the leeward breakwater. As the forces of flood and ebb were assumed to be equal and opposite, the result would be a thickening of the foreshore in the centre between the breakwaters. The instance of the sanding-up of a solid pier on the Nicaraguan coast cited by Mr. Hunter was most interesting. Mr. Hunter was perhaps a little hypercritical as to the phrasing of the opening sentence of the Paper. It might have been better to substitute for the words "the balance of the littoral forces," the words "the littoral regime." The Author's point was this :—Given a length of coast under conditions substantially stable, there was a balance of littoral forces, and at the same time constant movement. Equilibrium of condition and movement of coastal drift both existed, because month after month the regime of the coast was normal. If an obstruction, such as a groyne or solid pier, was built, immediately the balance was upset and new conditions were created. The action described by Mr. Inglis in his remarks as to Teignmouth was going on at the entrance of every exposed river-outfall and estuary. On the Sussex coast the River Adur ran approximately north and south, but on reaching the coast-line it took a sharp twist to the east before debouching into the sea. The outlet was driven to leeward, as described by Mr. Inglis. In the same way the River Ouse formerly discharged under Seaford Head, $2\frac{1}{2}$ miles east of the present largely artificial outlet. The same action might be watched going on in the neighbouring River Cuckmare.

The Author.

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[1] Minutes of Proceedings Inst. C.E., vol. xii. Plate 2.

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-