Mr. PARKES said he was sorry that the Author could not be present, but he should be glad to take advantage of any suggestions that might be offered, and as he was as responsible for the work as Mr. Price himself, he could give any explanations regarding it. The Author had been wise in confining the Paper to one feature in the scheme of harbour improvement at Kurrachee. The other parts of the scheme were of great interest, but were, at present, hardly adapted for the subject of a communication to the Institution. The results of the works of construction, though the works themselves were practically complete, were not yet fully developed. As explained, considerable improvements had been effected in the harbour. Reference had been made to the delay in the construction of the breakwater. In justice to Mr. James Walker, it should be known that this was not in accordance with his desire. Government overruled his advice in the matter, and only those works which increased the scour of the harbour had been carried out in the first instance; but their success was imperfect; and when the Government asked his advice after Mr. Walker's death, it was given most unhesitatingly in favour of the immediate construction of the breakwater. There was no great travel of sand coastwise; but whatever sand there was within reach of the waves was lifted by them and deposited as a steep ridge. When the scour caused by the formation of the groyne acted upon the bar, it made an attempt to drive a channel through, as long as fair weather lasted; but as soon as the monsoon came, the partially-formed channel was filled up by a narrow steep ridge. This went on for some time, and a great quantity of sand was washed out of the harbour and deposited in such a way as to lengthen the bar, so that the navigation was much worse than in the original state of the harbour. The breakwater was commenced in 1870; it was completed in 1875, and the result was quite in accordance with anticipation. As soon as shelter was given, the tendency to the formation of a ridge across the channel was stopped; the depth was rather greater after the monsoon than before, on account of the stirring up of the sand which helped the ebb tide to carry it out. Since the breakwater had been completed there had not been the slightest diminution of depth at the entrance. The entrance channel had been changed from a very circuitous one, with a depth of 14 feet at low water, and difficult of navigation, to a perfectly straight one, with a depth of 20 feet at low water, admitting the largest class of ships; and, as a rule, sailing ships could go in and out without the aid of steam. It was seldom that works of such character and extent had been carried out with so little modification of the original plan. A better description of them and their results could scarcely be found than in Mr. Walker's original report. The only modification from his plan was in regard to the delay in the construction of the breakwater, necessitating a recourse to dredging. If the breakwater had been previously in existence the increased scour would probably have formed a permanent channel, without the necessity of dredging.

The breakwater might be said to have no foundation. The outer half rested on quicksand, and the inner half on quicksand diversified by unyielding masses of rock. He had doubted the possibility of making a regular building upon it, and had looked forward to the first half of the breakwater being ultimately a random pile of blocks like those at Port Said and Alexandria. With the exception of the accidental removal of a few blocks from the outer end, in consequence of stormy weather before the necessary security had been completed, the outer half had received no damage. It had sunk bodily into the sand to the extent of about 3 feet at the maximum; but that was all the change. There was no bond between the two walls, and an opinion was at one time entertained that that might be a source of weakness. It had not proved so, because where the settlement was regular, as in the outer half, the two walls had not separated; on the contrary, they jammed so close together, that in some cases the upper edges of the blocks in the centre joint had been chipped. There was a little tendency towards canting over to seaward, as the sea side settled a little more than the harbour side. By far the greatest amount of settlement was in the first season. The process might go on for a few years longer, but he did not think it would be a serious matter. The very low level of the breakwater was another point worthy of notice. It was now at about half-tide level. There was a depth of 4 feet over it at high water, but it was perfectly effectual as a breakwater. Indeed the Author thought the wave falling over it rather tended to neutralise the undulation on the harbour side. The diagram of the waves (Plate 2) should not be looked at too critically. Their height had been accurately measured, but their thickness was of course very much a matter of guesswork.

Mr. Brooks said when the subject of the Kurrachee harbour was brought under the notice of the Institution in 1863, during the reading of a Paper on the Sind Railway,[1] he condemned the proposed plan for the works, and spoke in favour of a recommendation

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxii., pp. 451-479.

by Mr. Taylor, one of the hydrographers of the Indian Navy, that a pier should be made from the opposite shore to the eastward, and after passing over the Oyster Rocks should terminate rather beyond the head of Manora Point.[1] He also expressed the opinion that the construction of any breakwater at Manora Point would make the harbour of Kurrachee much more dangerous than it was before, and that opinion had been verified. The length of the dangerous sand had been nearly doubled since 1858, so that with a west or south-westerly wind a sailing vessel would have had the greatest possible difficulty in entering the harbour. He believed, the formation of the present useful channel was due to the dredging, and he should be glad to know how much money had been spent in that operation. Too much money could not be laid out in securing so noble an entrance to a harbour of such national importance.

Mr. JOHN FLEMING remarked that the defect of the earlier works was, that while during the fair season a certain improvement was observed at the entrance of the harbour, during the monsoon it was filled up again; but since the completion of the breakwater the channel had remained permanently open. During the last monsoon, a large steamer drawing 23 feet 8 inches passed out of the harbour with perfect ease, whereas in 1858 the official sailing directions declared it unsafe for vessels drawing over 15 feet at neap tides, and 17 feet at spring tides, even in fair weather, to attempt to enter or leave the harbour. This fact proved the works to be a great success.

Mr. REDMAN said there was one point of great practical interest as to which the Author might be able to give further information, viz., the displacement of the large masses of concrete. In a recent discussion upon the Papers on the Pier at Kustendjie and the Aberdeen Breakwater, the question was asked why the one should be so thick and the other so thin.[2] Sir John Hawkshaw then called attention to the dissimilarity of the two places—one in a tideless inland sea, and the other on a storm-beaten coast with a great rise of tide and an enormous offing. He also referred to the now celebrated concrete block at Wick, 45 feet in length, and 1,400 tons in weight, which went wandering about owing to the enormous power of the sea. Considering the fate of that block, and looking at the dimensions of the blocks displaced in the Kurrachee breakwater, the little journeyings of the latter should not occasion any

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxii., pp. 487, 488.

[2] *Ibid.*, vol. xxxix., p. 148.

surprise. The scantling of the block at Wick was not stated, but taking it at 24 feet each way, it would represent a resistance of 1½ ton per superficial foot. In the series of dynamometer experiments by Mr. Thomas Stevenson on the opposite Scottish coast, with an offing as great, a sea as deep, and waves as high, a maximum result was shown of nearly 3 tons per superficial foot.[1] Having regard to the depth of the sea, and the character of the wave as described by Mr. Price, there would possibly be an impact of 1 ton to the superficial foot; now looking at it in the most favourable way, the edge of each block, 8 feet by 4 feet 6 inches, only offered a statical resistance of 15 cwt. Mr. Stoney, in a recent Paper[2] of great interest, had given an account of concrete blocks, weighing 300 tons, which he had successfully laid at a great depth below low water for a sea-wall in the Liffey; and the success of that work had induced him to advocate, with great force and plausibility, the application of such a system to marine works. Without going into the question of the enormous increase in machinery, no doubt the same talent that devised the Titan, and manipulated the 27-ton blocks, would equally grapple with them if six times as large. This would do away with the confessedly weak point of the work, the open joint in the centre, which caused the resilience of the two halves of the breakwater. The thickness being increased 50 per cent., each block would be about 240 tons; and the 4 feet 6 inches being increased to about 7 feet, the block would require 1½ ton per superficial foot to move it, as compared with 15 cwt. Looking at the result of the movement of the block at Wick, where the offing, the depth of water, and the height of the wave were similar to Kurrachee, but where the rise of the tide was 10 feet, as compared with 7 feet 6 inches, it was clear that if the blocks in the Kurrachee breakwater were six times as large, and the thickness increased 50 per cent., they would not be more than equivalent to the impact of the 15-feet wave described in the Paper. He did not offer these remarks in a hypercritical spirit, but considering the results obtained by Mr. Stoney, and those accomplished by the Author with smaller blocks, he threw out these suggestions as hints for any future extension.

Sir Henry Montgomery had watched the progress of the Kurrachee breakwater from its commencement, and, in the position which he filled in the Council of India, had done all that he

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[1] *Vide* "Transactions of the Royal Society of Edinburgh," vol. xvi., part 1.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxvii., p. 332.

could to support Mr. Parkes, who had invariably expressed confidence in the principles on which he had acted, and had successfully overcome any little difficulties that had arisen. The breakwater was in full operation, and appeared likely to answer the purposes for which it was constructed. It was completed within the estimate—a rare occurrence either in India or in England. The free use of cement and of concrete as a substitute for cut stone had promoted the operations, happily brought to a close without a single fatal accident.

Sir BARROW ELLIS remarked that he was not able to criticise the professional details of the work; but he could describe the state of Kurrachee harbour twenty-four years ago. When he first went there, it was with difficulty that the smaller class of steamers entered the port except at very high tides and in very calm weather. It was then necessary for passengers to land in a small boat; and the mole not having been completed, the boat was insufficient to bring them to the jetty. When landing in 1851, he had to exercise considerable agility in skipping from stone to stone in order to get upon firm ground. That state of things continued for some years, and he well remembered the great interest felt when a single sailing vessel, drawing, perhaps, 17 feet of water, entered the harbour and left it again in safety. These works had had, throughout, the benefit of the experience and the advice of Mr. Parkes, who was so much concerned in the original plan, and also the almost uninterrupted superintendence of Mr. Price; and to those circumstances the success of the work might be greatly attributed. He could not share in the opinion expressed by a previous speaker, that the good effect produced was solely the result of the dredging. That operation, however valuable, was merely subsidiary, and it ought not to have the credit due also to the other greater works, which had not only made the channel, but kept it open.

Lieutenant-General TREMENHEERE desired to bear testimony to the zeal, the energy and the ability with which Mr. Price had carried out his arduous labours. He regretted that they should have produced such a strain upon his physical powers as to prevent his attendance on that occasion. His exertions had been fully recognised by the authorities in India, and he had no doubt that they would be as fully appreciated by his professional brethren at home. During the time he was Chief Engineer in Sind, the harbour works at Kurrachee were carried out by Mr. Price under his general supervision; he was therefore fully cognisant of the value of his labours. The statement that, before the breakwater was completed, vessels of a greater depth than 13 feet could not enter the harbour, demanded notice and correction. In 1858, before anything had been done to the harbour, the least depth in the entrance-channel, as shown on the chart, was $16\frac{1}{4}$ feet. The rise of ordinary spring tides was stated by the Author to be $7\frac{1}{3}$ feet, which would give an available depth at high water of $23\frac{7}{12}$ feet. The highest spring tides rose 12 feet, which would give a total depth, at such times, of $28\frac{1}{4}$ feet. He would be glad to know the depth of the present dredged-channel, the total quantity of material removed, and the expense incurred. He had no wish to offer any observations on the construction of the breakwater; but it had occurred to him that there were a few points of detail upon which it might be desirable to learn the opinion of Mr. Parkes; for instance, whether the blocks, instead of being set on edge in three courses, might not have been laid flat, and whether some bond might not have been provided. These were matters which, no doubt, had been duly considered, and there were probably sufficient reasons for the course adopted. He did not offer these remarks in a spirit of criticism, but simply to elicit information. He offered his cordial congratulations to Mr. Parkes on the completion of the work, and on his good fortune in having had the co-operation, in carrying out his views, of so able an engineer as Mr. Price.

Mr. Parkes gave some explanations, but the substance of these observations would be found embodied in his reply through the Secretary.

Mr. Harrison, President, said the Institution was greatly indebted to gentlemen like Sir Henry Montgomery, Sir Barrow Ellis, and General Tremenheere, who attended and took part in the discussions. With regard to the observations of Mr. Brooks, it should be remembered that a harbour was now formed, where there was none before, upon plans laid down many years ago by a former President of the Institution, Mr. Walker, and carried out under the able superintendence of Mr. Parkes. Whatever speculations might be made with regard to the adoption of another system, the fact was plain, that a successful operation had been accomplished. It was one of those cases which showed what the ingenuity of an Engineer could do in dealing with an entirely novel state of things. A practical lesson might be learned from it. There were frequent cases in which foundations had to be laid where there was no bottom. He had one such under his own superintendence, with which he hardly knew how to deal, the depth being 70 or 80 feet. He was proposing to deposit large masses of slag from ironworks, which could be obtained at a cheap rate, and when fully consolidated to build on the slag a quay-wall of concrete. The building of a superstructure of loose blocks suggested that at a future time, when the settlement was complete, they might be taken up and replaced in a perfect form. Mr. Parkes was to be congratulated that he had accomplished his work within his estimate. However careful Engineers might be, such a result was exceptional.

Mr. WILFRID AIRY remarked, through the Secretary, that he thought one of the most interesting features of the Paper was the account of the action of the sea upon the breakwater. It appeared that the blocks which were displaced by the sea were on the harbour side of the breakwater, and that the blocks on the sea side of the breakwater, even when left unsupported in consequence of the displacement of the blocks on the harbour side, remained firm. He considered this circumstance pointed clearly to the manner in which the dislocation of the breakwater took place, and he imagined that it was as follows:—The central longitudinal joint of the breakwater, either from settlement of the foundation or from having been originally left unfilled, got filled with water by a sea, and before the water so lodged in the joint had time to leak away, it was struck violently by the broken water from the succeeding sea. This would cause an instantaneous and violent hydraulic pressure between the blocks, which might easily be sufficient to thrust them apart, and ultimately to push the harbour-side blocks (which would be least supported by the sea) quite off the breakwater. As soon as this had happened, the outer row of blocks would be relieved from the hydraulic shocks from within, and would be comparatively safe, as the pressure would always be in the same direction. He was fortified in this explanation after an inspection of the diagrams and photographs exhibited by the Author. The natural conclusion from these considerations was, that the upper joints of breakwaters should be carefully closed, and if by settlement cracks were formed or joints opened, they should be at once filled up to prevent the lodgment of water in them.

Mr. RUSSEL AITKEN observed, through the Secretary, that when he visited Kurrachee, in 1866, although the steamer drew but 15 feet, it bumped heavily on the bar, which then showed no signs of improvement. At the request of the late Commissioner in Sind, Mr. A. D. Robertson, he wrote a memorandum, which had been published in the Government papers. In this report it was stated that, as the sand forming the bar must come from the westward, "the only means to get rid of Kurrachee Bar is to stop the sand going on to it" (from the westward, by constructing the Manora Breakwater) "and to dredge out the sand of which it is now composed." Up to this time, one of Mr. Walker's chief recommendations, viz., dredging on the bar, had been lost sight of, and scour only appeared to have been thought of. It was further pointed out in this Paper that, since Mr. Walker's report was written, the power of dredging-machines had so much increased, that in a work such as this it was better to trust to dredging than to scour, which was seldom or ever effectual in obtaining the depth of water necessary for navigation. He thought that the large expenditure incurred in diverting the waters passing through the Chinna Creek on to the bar might well have been dispensed with.

Captain E. K. CALVER remarked, through the Secretary, that various documents connected with proposed works at Kurrachee Harbour had been forwarded to him in May 1866 for an opinion; this had reference to the projection of the works, and not to their construction. The circumstances of the locality were peculiar. The periodical monsoon and its heavy seas, the subjection of the tides to local disturbing causes, and the apparent uncertainty connected with the current movements, all suggested a certain amount of doubt while drawing conclusions concerning improvement works; so much so that, in the absence of a careful study of all the features of the locality upon the spot, with the view, if possible, of tracing them to their several causes, any opinion about remedial measures must be general, and perhaps not very reliable. Be that as it might, after mastering the details of the documents referred to, he came to the following conclusions:—A conditional approval of an extension of the Keamari groyne, and a disapproval of the Manora Breakwater. Respecting this latter work, it was interesting to note that, in a letter of the 15th of March, 1864, Mr. Parkes stated his belief that the ground which led the late Mr. Walker to project the Manora Breakwater was not tenable, viz., "the existence of a shore movement of sand round Manora Point; for subsequent observations show that there is little, if any, such movement." It was noticeable, however, that in the Paper mention had been made of a diminution of depth, to a limited extent, in the shore angles of the breakwater, which at least proved that there had been a coast-drift from west to east of a certain amount, which might, in time, make its existence obtrusively felt. The breakwater had also attached to it the drawback of deflecting the flood past the entrance, so that the flood and ebb streams did not act in the same line over the bar—one of the objects generally sought to be effected by works. It had been stated by the Author that the breakwater had so far proved effectual in stilling the entrance-channel; but it was difficult to gather from this whether the nautical accessibility of the harbour had been improved thereby, enabling vessels to enter Kurrachee harbour with greater facility than had been the case before the breakwater was built. Considering as he did, that the breakwater was merely a prolongation of Manora Point—that it would neither interfere with, reduce, nor destroy, any agent to which the features about the promontory were owing—he could not resist the conclusion (nor did he now) that in time all the sandy accumulations which then existed about the Point would, in their general character, be reproduced at the end of the breakwater, with the additional drawback of their being further removed from the effect of the improved scour established by Keamari groyne. Time, of course, would alone show whether these views were correct. The first effects of the breakwater might be beneficial; but the permanent adjustment of the surrounding features to the new condition of things was the point to be regarded, and it was not till such equilibrium had been arrived at that the real value of the work itself could be determined. The special character of the case had already been mentioned; and the difficulty of forming an opinion about it deserving of confidence was further increased on account of the different views held as to the effective cause of the sandy features about Kurrachee Harbour. Colonel Tremenheere, the Chief Engineer at Sind at the time, held that a coast current from south-east to north-west (from the Indus) was an active agent of change in the locality, while Mr. Parkes, on the other hand, treated this as hypothetical; but it was upon correct information respecting such points as these that a reliable opinion must be dependent. Generally speaking, he held in 1866, as he held now after noting the contents of the Paper, that the adjustment of the length of Keamari groyne, a parallel work along the shore inside Manora Point, and vigorous dredging, were the measures most likely to meet the wants of the present and the future at the least cost. At the best, however, this was an opinion resulting from imperfect data, and was scarcely fitted to come into serious competition with that formed by Mr. Parkes, who had the advantage of an intimate acquaintance with the locality, and who had devoted to the case much careful study.

Sir JOHN COODE remarked, through the Secretary, that the mode of setting the blocks with greatly-inclined beds was not novel, this system having been adopted by Telford in a portion of the north-east pier at Peterhead. It was also recommended by Colonel Askwith, R.E., who probably was unaware of Telford's work at

Peterhead, to the Committee for the construction of a harbour of refuge in Dover Bay in 1846. Nevertheless, Mr. Parkes, as the Engineer of the Manora Breakwater, was entitled to the credit of having been the first to use this method on a large scale; but it was not applicable in all cases, although the principle was suited for adoption at Kurrachee.

The form of the setting traveller was new, and had apparently been successful; it appeared, however, to be capable of improvement, by placing the crab at the rear end and running the chain through blocks mounted on a small 'monkey' travelling frame, and thus removing a considerable overhanging weight. He was not prepared to assent to the doctrine that the absence of bond was an advantage, but the contrary; it would have been preferable to have carried each block completely across the work from the sea face to the harbour face without any vertical joint, modifying the dimensions to meet this change. The work consisted, in fact, of two entirely independent walls, each 12 feet thick. Such a structure was not adapted to withstand the shock of heavy 'waves of translation,' such as were constantly encountered by sea-works in stormy latitudes. The walls might for a time resist the force of the 'waves of oscillation' ordinarily experienced at Kurrachee during the south-west monsoon; but the repeated removal of blocks, and the necessity for connecting those at the outer end by chain ties, seemed to indicate a want of strength in the work. These remarks were justified by the disturbances in the finished work, and did not refer to those which might have happened to unfinished portions in course of construction, when all sea-works were, of necessity, for a time, in a vulnerable condition. There seemed ground for apprehension that this breakwater in its finished state might hereafter suffer material damage from some gale of extraordinary force, such as would be found to occur once only in a long series of years.

The frank and explicit description in the Paper of the damage done by the sea from time to time, and the details of quantities and cost in the Appendix, were features especially worthy of commendation.

Mr. J. N. Douglass remarked, through the Secretary, that an account of the exact expense of such a work was especially interesting at the present time, when the more extended use of concrete blocks of large size was receiving considerable attention. The dimensions of the blocks adopted by Mr. Parkes appeared to be just sufficient to withstand the seas to which they had been exposed at Kurrachee; but there the seas were not nearly so violent as on many parts of the coast of Great Britain. Heavier blocks having a larger margin on the side of safety would, in his opinion, have been preferable, where the exact force to which the work might be exposed could never be positively determined. The absence of bond, both longitudinally and laterally, deserved attention. With such a work set on a rubble bank, thrown in upon the natural bottom, he agreed that longitudinal bond was unnecessary, and would be, probably, mischievous; but lateral bond seemed to be especially advisable. The pier at Alderney was an instance of the want of such bond. Settlement of the sea side of the work had occurred there, and this being imperfectly bonded with, and supported by the inner portion, caused serious fractures and mischief. In the Manora Breakwater good lateral bond might have been obtained, at a small percentage of additional cost in providing more powerful machinery, by the adoption of blocks of the same thickness, but in one length for the whole width of the breakwater, and in two, instead of three tiers in height, one block being thus equal in weight to three of the present blocks, or about 81 tons each, and by moulding them with a groove and tongue at the joints. This groove and tongue, besides acting as a guide for each block in lowering it to its bed, would give additional lateral stability to such a work, and check the direct drift of the heavy seas through the joints.

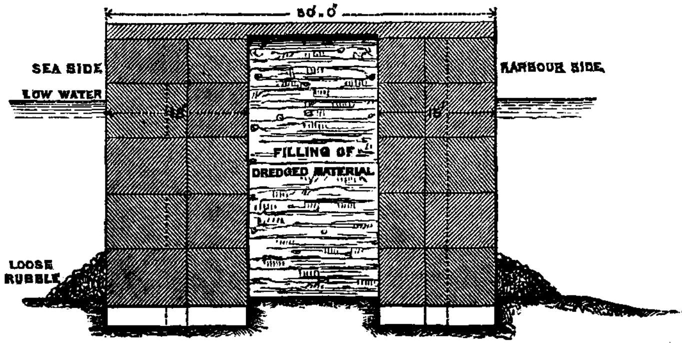
Mr. Alfred Giles stated, through the Secretary, that he did not agree with Mr. Brooks in believing that the harbour mouth at Kurrachee could have been kept continuously open without the shelter of the breakwater at Manora Point. The travel of sand along the coast from the westward would, during heavy weather, naturally tend to fill up any artificial channel round the Point, and the dredging operations would consequently have to be renewed after every monsoon; the entrance to the harbour would therefore have been not only uncertain and precarious, but expensive to maintain. He would have preferred to have given the breakwater a little more slant to the south, thus making it nearly parallel with the entrance, and better able to withstand the heavy seas by receiving them at a more acute angle. Great credit was due to the Author for the rapidity and economy with which the works had been carried out. He approved of the method of setting the blocks at a slight angle; at the same time he considered the absence of bond in the centre disadvantageous, and he feared the damage to the work already occasioned by exceptional weather proved the section to be rather light for the heavy seas the breakwater would have to encounter.

Captain E. Giles, I.N., who, from 1857 to 1873, had filled the office of Master Attendant at the Kurrachee Harbour, remarked, through the Secretary, that in 1857 the east (main entrance) channel took a circuitous bend round the tail of the bar or sand spit extending from Manora Point to the eastward. In this channel the average depth varied from 18 feet to 19 feet at high-water neaps, and from 21 feet to 23 feet at high-water spring tides. With these depths it was, as a rule, possible in the fine weather season (September to May) to cross the bar at high water, with vessels drawing from 17 feet to 21 feet, according to the tides and the actual state of the weather on the day of entry. From May to September a different state of things prevailed, from the south-west monsoon rolling up so heavy a swell as to make it a necessity that vessels crossing the bar should have a depth of at least from 6 feet to 7 feet of water under them. At this season then the extreme depth at which ships could enter or leave port was from 13 feet to 17 feet at neap, or spring tides respectively, and even at these depths they were fortunate to cross the bar without bumping. In addition to this east channel (as above) a slight depression ran across the bar spit, close under Manora Point, very nearly on the site now filled by the new channel. This west channel, with some 3 feet to 4 feet less water in it than the east channel, lay well to windward, and was used by vessels of light draught, which were enabled to run through it into port under sail, with a free wind and following sea; it was useless, however, to outward-bound ships, as the swell directly heading them caused heavy pitching and consequent dangerous bumping. From the above it would be easily understood that the port of Kurrachee, as it existed before the improvement works commenced, was not capable of maintaining a regular trade at all seasons of the year by vessels of large size; and further, the safety of those ships that did use the port was a constant and never-ceasing source of anxiety to the harbour authorities. The improvement works had changed all this, or rather the Manora Breakwater had done so. The first work of improvement undertaken was the Keamari groyne, completed in 1863. By the greatly-increased scour produced by this work, large quantities of sand were removed from the harbour to be deposited in both the entrance channels, adding for a time greatly to the difficulties of navigation. This temporary evil reached its climax in 1865–66, when matters, although getting worse in the east channel, began slowly to mend in the west channel. The improvement in the latter channel it was considered advisable to aid by dredging, and to a certain extent the result was satisfactory. It was, however, soon seen that, without shelter from the south-west monsoon swell, the depth necessary for large vessels could not be maintained throughout the year, and the breakwater, which had effectually given this shelter, was commenced. In the meantime the tidal scour, being diverted, as it had been always hoped and intended, into the new channel, the eastern entrance continued to silt up, and in 1871 the buoys were removed, the use of this channel was abandoned, the whole traffic of the port being conducted through the new channel. In 1873 the breakwater was completed, and by its aid, together with scour and dredging, this channel, which had been year by year improving, since the commencement of the breakwater, was, for the first time, maintained through the south-west monsoon with a depth in it of 20 feet at low water. This depth had since been maintained, while the channel had been widened and improved by dredging to an extent sufficient to permit laden vessels of the largest class to enter or leave port at all seasons of the year. The new entrance to the port being then all that could be desired, it only rested with the authorities to so far improve the interior, either by docks, as proposed by the late Mr. Walker, or by dredging, as to enable Kurrachee to accommodate a trade of the largest kind.

Mr. HAYTER observed, through the Secretary, that Sir John Hawkshaw and Mr. Charles Hutton Gregory, Past-Presidents Inst. C.E., had been consulted in 1873 by the Molehead Commissioners of Bridgetown, Barbados, on the best means to improve the harbour of Bridgetown. Thereupon they recommended the construction of a pier or breakwater, with sloping or inclined courses of concrete blocks, the details of which he had worked out. The courses, however, instead of being without bond, as in the Manora Breakwater, had been bonded as far as practicable as shown in Figs. 1, 2, 3. There being no exceptionally heavy seas at Bridgetown, the smaller blocks were intended to weigh about 25 tons, and the larger blocks about 30 tons, and the bond was nowhere less than 3 feet. The courses were to be laid at an angle of 60°, instead of 75° or 76°, as in the Manora Breakwater. It was believed that by bonding the blocks, and laying them at a flatter angle, a more stable structure would be insured. The flatter angle would render it necessary to lengthen the jib of the 'Titan,' or overhanging crane used in setting the blocks, which would increase the size and cost of the machine, yet it was considered that this would be more than compensated for. Inclined courses might be useful when the foundation was bad, as the structure could better settle down without injurious displacement or cracking.

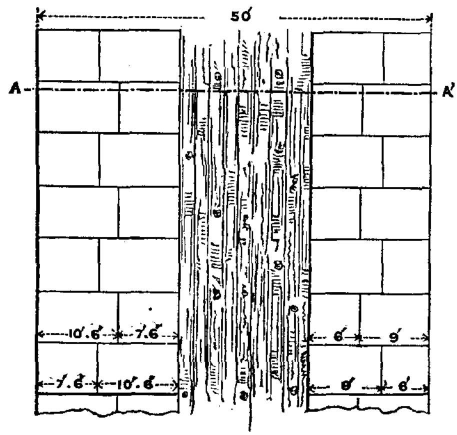
It might be well, however, to instance a case in which horizontal

Fig. 1.



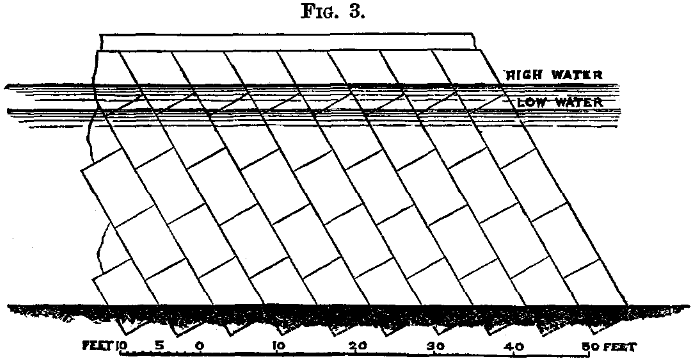
Cross section on line AA'.

Fig. 2.



Plan.

Fig. 3.

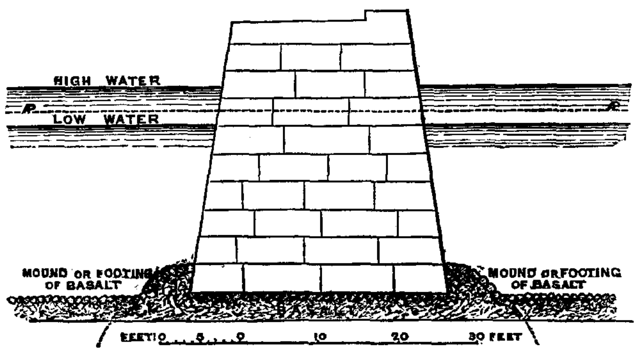


Elevation.

Breakwater at Bridgetown Barbados.

courses were adopted in piers built on a very unfavourable foundation consisting of quicksand, the case in question being the North Sea piers of the Amsterdam canal, which he had studied and which had been designed by Sir John Hawkshaw. (Fig. 4.) It was attempted at first to erect these piers by a timber staging of screw piles, but a slight disturbance of the sea excavated a hole round the piles, laying them bare, or sufficiently so to destroy the staging. This plan, therefore, had to be abandoned; and it was then tried to set the concrete blocks by a 'Titan,' after partially excavating the sand. It was hoped that when the bottom blocks had been set they would, notwithstanding the disturbance of the sand, find a bed which could be levelled, and upon which the structure could be raised. This mode of procedure, however, did not answer

Fig. 4.



Amsterdam Canal—North Sea Piers.

satisfactorily; upon which Sir John Hawkshaw determined to substitute for the bottom course a layer of basalt thrown in 'pierre perdue.' The width of this mound was about three times that of the pier at the base, so that when the trench was excavated by the sea at the sides of the mound, the basalt fell into the hollow until it formed its normal slope, as shown by the dotted lines, leaving a central horizontal portion upon which to build the pier. This plan secured a good foundation, and it had been found that as the piers advanced (and they were now nearly completed) the trench, which in places had been no less than 26 feet deep, gradually filled up.

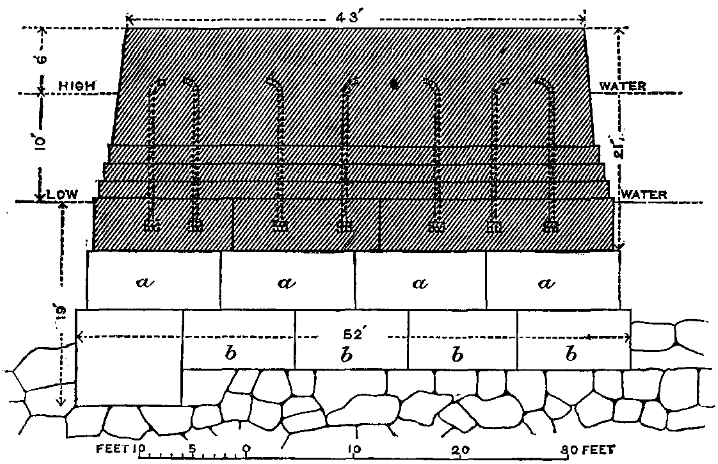
The system pursued at Kurrachee would probably fail where the seas were very heavy—as for instance at Alderney, or even at Holyhead—unless much heavier blocks were used, and they were bonded. At the Manora Breakwater bonding might perhaps have been introduced with advantage. It was satisfactory that the work had been stated to be stable, and it might therefore be assumed that the expectations of the designer had been realised.

Mr. J. A. McConnochie stated, through the Secretary, that he had been engaged under the late Mr. Walker on the early designs for the Kurrachee Harbour improvements, and had been much interested in hearing periodically, during the progress of the works, of the success of the design for the Manora Breakwater; and he considered the information furnished by the Paper to be of unusual value to all engaged in sea works. The details of the Manora Breakwater had been designed by Mr. Parkes after the decease of Mr. Walker, and the novelties which Mr. Parkes had introduced in the designs had attracted the attention of all persons experienced in the construction of breakwater works, in exposed situations, on a rubble base. Whether the cost of this work, the rapidity with which it had been constructed, or the small amount of sea damage which had resulted, were regarded, they alike reflected the greatest credit on Mr. Parkes, and on Mr. Price who had executed the works; and proved that the principles of construction were correctly suited to the circumstances. Few, if any, sea works that he was acquainted with, unless it were at Alderney and Wick, were exposed as this to a lengthened hammering by waves measuring 15 feet from trough to crest. The two main features in this work which appeared to be the key to its success were the absence of horizontal bond, and the low level adopted for the top of the superstructure. The absence of horizontal bond admitted of the settlement, amounting to 3 feet, taking place without dislocation of the superstructure; the settlement, therefore, which had been the fruitful source of failure in works of this character with horizontally bonded masonry, was here harmless. The low level of the top of the breakwater, nearly 3 feet below high water, prevented the scooping away of the base and foreshore by the back-lash or recoil of the sea, an invariable feature with the high superstructures so often adopted in breakwaters, causing danger to the work, and heavy cost in maintenance. In this case the foreshore, of stones not exceeding 4 tons in weight, remained undisturbed at a depth of 15 feet at low water, and from his experience of high superstructure works, in anything approaching the monsoon exposure at Kurrachee, a foreshore with stones of this weight could not be maintained at so high a level. The observations recorded in the Paper showed that the shelter afforded by the breakwater at this low level enabled an open boat to approach it within 100 feet at the height of the monsoon, and that it efficiently served the purpose for which it was designed. The middle line joint was doubtless a weak point, but this applied only to the top course, and principally on the harbour-side row of blocks, and the chain ties adopted at the outer end, which might with advantage be adopted throughout, effectually secured the work, while they admitted of unequal settlement between the sea and harbour rows of blocks. He believed this system of masonry, dispensing with horizontal bond, was the correct construction for a superstructure on a base of this character, and might be adopted with economy and advantage on other and more solid foundations under water.

The remarks of Lieutenant-General Tremenheere had reference more to the whole scheme of the Harbour improvements than to the immediate subject of the Paper, and indicated that he still considered the improvement in the entrance to be due to dredging alone. Without the shelter afforded by the Manora Breakwater the straight deep-water channel across the bar, which had so materially improved the entrance, would have been filled up to a great extent with the sand disturbed by the waves of the first monsoon after it had been dredged. Much of the cost of the dredging would have been saved if the breakwater had not been so long delayed. Judicious dredging, combined with the shelter of the breakwater, had here been attended with results as successful as those obtained, under somewhat similar circumstances, from the works at the mouth of the river Tyne. The Kurrachee works as a whole had, under the careful direction of Mr. Parkes, fully realised the expectations of the late Mr. Walker, and they afforded an instructive example of harbour engineering.

Mr. David Stevenson remarked, through the Secretary, that at the close of 1867, after five seasons' work, the superstructure of Wick breakwater had been built to a distance of 820 feet from high-water mark, and the rubble base had been deposited 250 feet farther, the total distance to the end of the staging being 1,050 feet; and that up to that period the works had suffered very little damage from storms, the amount expended in repairs being only a few hundred pounds. The superstructure of the breakwater was, in 1868, extended to 1,050 feet into the bay, the extreme length attained. Subsequently a succession of storms carried away a length of 223 feet from the extremity, and the breakwater was at present 827 feet long, terminating in a depth of 5 fathoms at low water of spring tides. The extraordinarily heavy action of the sea was not fully developed until the work had been so far extended that the curved wave which entered the bay impinged on the breakwater nearly at right angles to its line of direction. This outer and exposed part of the breakwater was founded on a mass of rubble at the level of nowhere less than 18 feet below low water of spring tides. The breakwater was carried up to the level of 11 feet above high water, where it was 43 feet in breadth, and on the seaward side there was a parapet wall measuring 12 feet thick at the base and 9 feet at the coping which was 21 feet above high-water level. This breakwater was very much stronger than that proposed for Wick Bay by the Harbours of

Fig. 5.



Wick Breakwater.

Elevation of the end, showing, by diagonal shading, the mass of 1,350 tons removed entire by the waves.
a a. Course of 80-ton cement blocks also removed by the sea.
b b. Course of foundation 100-ton cement blocks not moved by the sea.

Refuge Commission, in 1859. It had been founded at 18 feet below low water instead of 12 feet; it had been carried 11 feet instead of 6 feet above high water, and the areas of the sections of the two breakwaters were as 213 to 148 square yards, or as 1·43 to 1. In all its dimensions therefore the breakwater, as executed, was a far stronger work than that proposed by the Commission. The height of the waves by which the works had, on various occasions, been assailed, and which had carried away the outer portion of the work, had been estimated by the Resident Engineer at 42 feet from crest to hollow. They passed over the top of the parapet in masses of solid water estimated from 25 feet to 30 feet deep, and, as ascertained by photographic views, the clouds of spray were projected to a height of not less than 150 feet. During one of these storms, two stones, of 8 tons and 10 tons weight respectively, had been carried over the parapet and lodged on the roadway of the breakwater. He was not aware of any harbour work which had been subjected to such powerful and destructive waves, of a magnitude, moreover, disproportioned to the normal depth of the water in Wick Bay. The experience gained at Wick had proved beyond question that these waves did not affect the foundations of the walls, which had been founded at the level of 18 feet below low water, all the damage having been confined to the superstructure, and extending about 10 feet under low water, below which level the work was unharmed. Had the superstructure, however, resisted the force of the waves it was impossible to predict what might have been the result of such prolonged severe action upon the rubble base, as the failure of the upper work certainly afforded immediate and considerable relief to the shock on the foundations. After unsuccessfully struggling against repeated assaults of such seas, which were especially severe on the outer extremity of the breakwater, it was resolved in 1871 to construct a termination, by depositing three courses of 100-ton blocks on the rubble base, as a foundation for three courses of large flat stones, surmounted by a monolith of cement rubble built *in sitû*. It was hoped that the precautions used would form a protection against further damage to the exposed outer end of the breakwater, but in December 1872 nearly the whole of the outer protecting work was carried away. The destruction of this work was thus described in a Report by Messrs. Stevenson to the Directors of the British Fishery Society :—" The end of the work was protected by a mass of cement rubble work. It was composed of three courses of large blocks, of 80 to 100 tons, which were deposited as a foundation on the rubble. Above this foundation there were three courses of large stones carefully set in cement, and the whole was surmounted by a large monolith of cement rubble measuring about 26 feet by 45 feet by 11 feet in thickness, and, at 16 feet to the ton, weighing upwards of 800 tons. This block was built *in sitû*. As a further precaution iron rods, 3½ inches in diameter, were fixed in the uppermost of the foundation courses of cement rubble. These rods were carried through the courses of stonework by holes cut in the stone, and were finally embedded in the monolithic mass which formed the upper portion of the pier. The arrangement described would be readily understood from Fig. 5. Incredible as it might seem, the huge monolithic mass succumbed to the force of the waves, and Mr. McDonald, the Resident Engineer, actually saw it from the adjacent cliff being gradually slewed round by successive strokes, until it was finally removed and deposited inside of the pier. It was not for some days after that an examination could be made of this singular phenomenon, but the result only gave rise to increased amazement at the feat which the waves had achieved. It was found on examination, by diving, that the 800-ton monolith forming the upper portion of the pier, which the Resident Engineer had seen in the act of being washed away, had carried with it the whole of the lower courses which were attached to it by the iron bolts, and that this enormous mass, weighing not less than 1,350 tons, and presenting an area of about 496 square feet to the sea,[1] had been removed *en masse*, and was resting entire on the rubble at the side of the pier, having sustained no damage but a slight fracture at the edges. A further examination also disclosed the fact that the lower or foundation course of 80-ton blocks, *b b*, Fig. 5, which were laid on the rubble, retained their positions unmoved. The second course of cement blocks, *a a*, on which the 1,350 tons rested, had been swept off after being relieved of the superincumbent weight, and some of them were found entire near the end of the breakwater. The removal of this protection left the end of the work open, and the storm which continued to rage for some days after the destruction of the cement-rubble defence, carried away about 150 feet of the masonry, which had been built solid throughout the whole breadth of the breakwater and set in cement. The same remarkable feature of former damage was strikingly apparent in the last damage, the foundations even to the outer extremity of the work remaining uninjured."

On his first visit to the spot he found that the 1,350-ton mass had, after being moved from its bed, settled down on the rubble quite clear of the inner face of the breakwater. As soon as the weather permitted, the work of restoring the protection thus carried away was resumed, and completed in 1873. In making this restoration much the same style of construction, as formerly, had been adopted. Two courses of 87-ton blocks were built on shore and floated out, and deposited on carefully-levelled foundations in the débris that had been left unmoved by the sea. The blocks

[1] The lower courses to which the monolith had been bolted extended across the whole width of the breakwater, but did not extend so far as 26 feet lengthwise, which was the length of the monolith.

forming these two courses were connected together by iron rods, $3\frac{1}{2}$ inches in diameter, built into them and extending upwards so as to lay hold of the upper monolith of cement rubble which had been built *in situ*. The mass of masonry forming the present termination of the breakwater contained about 1,500 yards of cement rubble, the weight of which was about 2,600 tons. Whether or not the billows known locally as the wild "rollers" of Wick Bay would leave this mass of masonry undisturbed remained to be seen. Mr. Stevenson could not avoid directing notice to the action of the British Fishery Society under circumstances of great difficulty and discouragement; the directors having never shrunk from endeavouring to carry out the object they had in view so long as funds remained at their disposal. Messrs. Stevenson's recommendation to deposit large concrete blocks in front of the outer part of the breakwater, as an additional protection, which had been approved of by Sir John Hawkshaw, Past-President Inst. C.E., and Mr. Rendel, had not, in consequence of want of funds, been as yet accomplished.

Mr. B. B. Stoney observed, through the Secretary, that the Manora Breakwater belonged to the class with vertical sides, but that it differed from the ordinary section in the top being near the level of high water, in place of extending many feet above it. This greatly reduced the cost; and as a wave screen, in that particular locality and with the ordinary direction of the monsoons, the Manora Breakwater appeared to have been fairly successful, for the Author stated that, in the height of the south-west monsoon, open boats approached within 100 feet of the inside of the breakwater. It should not, however, be forgotten that one of the collateral objects of an ordinary breakwater was to act as a wind, as well as a wave screen, and in most situations, with storms coming in various directions, a breakwater reaching only as far as high water would not answer that purpose.

In consequence of its peculiar mode of construction, and the waves breaking over it in every storm, the destruction of the Manora Breakwater could not be regarded as a very remote contingency—unless, indeed, the heavy plant used in its construction were kept constantly on the spot, and repairs were effected each fine season; for, from the Author's description, it appeared that a large number of blocks were annually displaced, besides settlements, movements and disturbances taking place of a peculiar and critical nature. Neither did the cost of the plant and the temporary works appear to bear out the Author's statement, that the stability and cost of the work had been such as to warrant the construction and the means adopted. A large quantity of the plant was second-hand, and the work was debited with only one-fourth of its first cost; but in making comparisons with other systems of construction, it was fair to calculate the cost of the plant when new, as getting the use of second-hand plant was merely a matter of luck. The cost of plant and works, other than the permanent work, or the sum which was expended on preliminary expenses, experiments and surveys had been as follows:—

	£.
Special plant	15,747
Plant transferred	19,427
Office, stores, workshops, landing pier, &c.	10,269
Approaches	3,335
Concrete station	1,371
Block ground	2,399
	£52,548

In other words, £52,548 had been expended on plant and auxiliary works, to execute £55,579 worth of permanent works. When Mr. Stoney's Paper, on the construction of marine works with blocks of large size,[1] was read at the Institution in 1874, Mr. Parkes took exception to the cost of the special plant and auxiliary works used in Dublin for the 350-ton blocks, which amounted to £33,847, and claimed superior economy for the Kurrachee system; but it now appeared that the corresponding item for the latter work amounted to £52,548. Supposing the section of the superstructure adopted at Kurrachee to be the correct one, Mr. Stoney submitted that a permanent wall of the same section could be constructed, according to his system, with one hundred and fifty large blocks. Should any local settlement of the rubble base take place, it would only slightly affect a 350-ton block, 24 feet wide at the base, 24 feet high, and 10 feet long in the direction of the breakwater. Each individual block might settle slightly, but it would not split down the middle, or be washed into the harbour, or grind against its neighbours, or require costly plant to be maintained on the spot to pick it up and replace it in the breakwater.

Mr. Vernon-Harcourt observed, through the Secretary, that the method of construction adopted for the breakwater appeared very good; obviating the necessity of staging, which was so liable to damage from the sea, and often proved a cause of delay: though novel as a whole the position of the blocks resembled that adopted

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxvii., pp. 332–354.

at Kustendjie, and the 'Titan' was similar in principle to a 'Samson' which had been in use for many years at Alderney. The system seemed very suitable for jetties and breakwaters where a large expenditure on plant was undesirable; and the rate of execution was specially remarkable, exceeding the usual rate of progress of breakwaters, though a continuous spell of fine weather for four months in the year doubtless contributed to this result. The damage caused during the monsoons appeared to be due to unequal settlement, aided by a want of connection between the upper blocks of each set. Unequal settlement alone had not always led to damage, as the breakwater at St. Catherine's, Jersey, exemplified. The experience gained at Kurrachee tended to show that, in similar constructions, it would be desirable to connect the upper row of each set of blocks with each other, and with the course below; this might be done by bedding the top row of blocks in cement on the lower course, and also filling in the longitudinal joint between them with cement, leaving the joints across the breakwater open, so that each set of blocks would continue disconnected, but the two upper rows of each set would be united into one block. This would diminish the rapidity of execution, as the top blocks would have to be set near the time of low water; but in the present instance it might not have done so very materially, as the work was delayed by the excavation for the foundation course; and most breakwaters would have to be raised higher above the sea-level, so that the bottom of the top course would be ordinarily higher above low-water mark. It was to be hoped that the experience as to deposits at Kurrachee would not resemble that at Port Said, where a similar scour took place during the construction of the jetty, and a similar refilling afterwards, and where, subsequently, the deposit so much accumulated along the inner side that dredging had been resorted to for removing it.

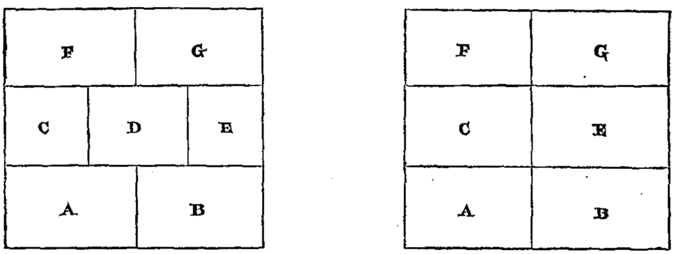
Mr. PARKES, in reply, said the remarks on the Paper might be divided into two heads: First, comments on the results of the improvement works generally, and on the effect of the breakwater especially; and, secondly, on the construction of the breakwater itself as a work of art. Applying himself to the first of these heads, he would refer those who doubted the reality of the benefits accomplished to the clear and explicit statement of Captain Giles, the late Master-Attendant of the Port, who had been intimately acquainted with the harbour before the works were commenced, in its transition period while the works were in progress, and in its present state since the works were completed. With regard to the share which the breakwater had taken in producing this result, General Tremenheere and Mr. Brooks appeared to deny it altogether; and their opinion was supported, in a qualified way, by Captain Calver, who in 1866 had recommended, in preference to it, dredging and an extension of the East Pier. In the determination of this point, almost everything depended on the question of the origin of the bar. As to this, some originally held that it was a deposit from the ebb-tide current, and the Layari river had been indicated as the source of the deposit. Others attributed it to the meeting of the ebb current with a supposed alongshore current from the westward; while a third party contended that it resulted from the meeting of the ebb-tide current with the monsoon swell. Detailed surveys and observations soon proved that the conditions necessary for the formation of a bar on these theories did not exist, while facts were obtained sufficient to bring the explanation within precise limits. During the south-west monsoon, Manora Point was surrounded by a heavy surf, formed by the breaking of the ocean waves on the shallow bottom near shore. Every broken wave tore up sand from the bottom, and carried it on shorewise until, rounding the east side of the Point, it spent itself in the sheltered area, and dropped the sand which it held in suspension. The sand thus deposited formed, in course of time, a shoal, on which in turn more waves broke, and it assumed under their action the characteristic form of a ridge with deep water on either side. Now this action, under which the bar was in a state of continuous, though possibly very slow growth, would not be prevented by an increase of scour or by dredging. All that one or the other could do would be to establish a counteracting operation. If, however, the belt of surf were divided by an extension of Manora Point, and the new extremity were planted at such a depth that the waves were no longer broken on the bottom (and thereby converted into waves of translation for the movement of sand), the conditions necessary for the growth of the bar, or its reproduction if once removed, would be annihilated. From this it would be seen that the object of the breakwater was to prevent the re-formation of the bar when it had been removed by other means. Now what were those other means? Contrary to the advice of Mr. Walker and Mr. Parkes, the Government, in the first instance, tried scour alone. But the scour brought with it an immense amount of deposit—new food for the bar so long as the conditions for the formation of a bar existed. While those conditions were in abeyance—during the fair season—the scour did its work; but the first monsoon re-established the conditions, and the ridge was re-formed, and higher than before. But the scour had not been idle; it found its outlet elsewhere, and its power for future action on the bar was gone. The old circuitous channel was reopened; and it was several years before the crest of the bar was again broken down. Had the breakwater been in existence when the scour caused by the Keamari Groyne was directed on the bar, the direct channel which began to form in the fair season of 1863 would have been maintained, and dredging would have been unnecessary; but the only chance for prompt action by scour was lost, and either dredging, or a very long period of time for the scour to do its work, became necessary. The former alternative was wisely chosen; 646,000 tons of sand were removed at a cost of £29,600, and the experience of three monsoons bore testimony to the permanency of the result. The total cost of the improvement works had been £450,000, of which about one-half had been especially devoted to the entrance, so that the proportion of £29,600 to the whole justified Sir Barrow Ellis's remark that dredging was only a subsidiary operation. Captain Calver had suggested the possibility that the beneficial effect of the breakwater was only temporary, and that the original state of things at the end of Manora Point would be ultimately reproduced at the end of the breakwater; but he thought that in putting forward this suggestion, sufficient weight had not been given to the essential difference between the end of a headland terminating in shallow water, and the end of a pier standing in comparatively deep water. In the former case the broken waves (of translation) were a continually disturbing force; in the latter case the unbroken waves (of oscillation) had little or no effect on the bottom.

He now passed to the question of construction. The system adopted had been undoubtedly an innovation, in the substitution of detached masses, depending for stability on their own weight irrespective of one another, for a continuous structure of masonry of which the rigidity was greater than the cohesive strength. It was gratifying to find that the correctness of this principle had been admitted, either expressly or by implication, by all who had taken part in the discussion. No one expressed a preference for the time-honoured system of horizontal beds and vertical joints well alternated in the successive courses. All went some way with the Author and Mr. Parkes, although not all agreeing in the expediency of the details that had been adopted. The suggestions related chiefly to the use of larger blocks, to bonding together the two walls, and to tying together the upper blocks of the two walls. With respect to the first suggestion, made in different forms by Mr. Stoney, Mr. Redman, and Mr. Douglass, there could be no doubt that, from one point of view, the larger the blocks the better, the only limit being that they should not be too large for the cohesion of the material, and he would assume (though with a reservation if the argument should be carried into greater detail than was his present intention) that that limit had not been reached by the authors of any of the suggestions. That one point of view was stability. A block was stable in proportion to its height and in proportion to its dimensions transverse to the pier, but not in proportion to its dimensions parallel to the line of the pier. A remarkable illustration of this truth was shown in the fact that in the Manora Breakwater a solid mass of concrete, occupying the space of three blocks, and therefore of a weight of about 81 tons, had been displaced, while the 27-ton blocks adjacent to it on either side were unmoved. It was three times the weight of a single block, but, being at the same time three times the length, had three times the disturbing force brought to bear on it, while the elements of stability—height and breadth—were not increased. It was of importance, then, to bear in mind that weight simply was not a true measure of stability. The true measure was weight per lineal foot measured along the pier. From this one point of view, therefore, Mr. Parkes admitted that the larger the blocks the better; but there was another point of view, that of cost. Up to a certain point, the larger the blocks the cheaper would be the work; but there appeared to be a limit to this, and if that limit was beyond the minimum required for stability, further increase in the size of the blocks would be unjustifiable. He would assume, what appeared to be the general conclusion, and what certainly was his own, that the blocks at Kurrachee were practically stable; the question then was, would any advantage be gained by making them larger? Of all the alternative plans suggested, the only one based on an accomplished work was that of Mr. Stoney, who appeared to prefer the plan he himself had so successfully carried out at Dublin. That plan had already been laid before the Institution, and was most deservedly commended; but on the question of cost and rapidity of execution, it compared unfavourably with the plan adopted at Kurrachee. Mr. Stoney quoted some figures in opposition to this conclusion; but if the Dublin plant for lifting, conveying, and setting the blocks, had been substituted for the Kurrachee plant applicable to the same purposes, the charge against the Manora Breakwater would have been £66,548, instead of £52,548. Besides this, it was considered by the highest authorities that, however admirable might be Mr. Stoney's plan for a sheltered situation, it was not practicable in an exposed position like that of the Manora Breakwater.

The suggestions of Mr. Redman and of Mr. Douglass had been made in general terms, and it would be unjust to compare such hypothetical schemes with the system adopted in a completed work. Mr. Redman would employ blocks of 240 tons, and Mr. Douglass blocks of 81 tons. As to the correctness of the principle Mr. Parkes concurred. The question was as to the practicability of their application, except at an expense disproportioned to the advantage. He was not prepared to deny the practicability of a system of land carriage for such blocks; but such a system would not be a mere extension of the Kurrachee system, it would be entirely novel. A setting machine might be devised capable of putting such blocks in place; but it would be no more like the Kurrachee 'Titan' than the latter was like its puny progenitor (as Mr. Vernon-Harcourt suggested it to be), the Alderney 'Samson.' Were the Kurrachee system modified so as to make it applicable to larger blocks, it would lead to questions of complication of machinery and strength of material which, in the absence of a definite plan, would seem to place such general suggestions beyond the pale of useful discussion. He had much pleasure in mentioning that his guiding precedents in the size of the blocks, and to a great extent in the handling of them, were furnished by the practice of Mr. P. J. Messent, M. Inst. C.E., at the Tyne piers, where blocks of 35 tons had been previously in use.

He now passed to the question of bonding the two walls together. In favour of this modification there was a strong concurrence of opinion of the highest authorities. General Tremenheere, Sir John Coode, Mr. Douglass, Mr. Giles, Mr. Hayter, and, through him, Sir John Hawkshaw and Mr. Gregory, were a formidable array; and Mr. Parkes freely admitted that if this discussion had taken place seven years ago, he would not have felt justified in opposing his own opinion, as he then held it, to such a weight of authority. He was now, however, thankful that he had not been exposed to such a trial. The opinion he then held had been strengthened by experience into a settled conviction, and he felt justified in maintaining it against the combined, but, he submitted, as yet untested, opinions of those high authorities. He laid claim, however, to no special prescience, for he had formed his original conclusion on reasons very different from, and less cogent than, those which had subsequently confirmed it. His original idea was simply of two walls, placed close together and back to back, without any hearting between them, because the 24 feet of double wall was wide enough for his purpose. Then the most solid form for each one of such walls seemed to be a pile of three blocks, of equal size. A middle course of three blocks to extend across the two walls was considered, but rejected on the grounds that it was impossible to bed a block (when uncemented) on two blocks so solidly as on one; that if a block of 27 tons were not too large for the work, then one of 18 tons would be too small, and a source of weakness; and that, inasmuch as it would cost as much to set a block of 18 tons as one of 27 tons, having to set seven blocks instead of six would add one-sixth to the total cost of setting. These reasons seemed to outweigh any real advantage to be gained from the 'bond course,' and they were quite independent of any question of the effect of bad foundation; indeed, he was prepared to find that no precautions could insure permanency of form in the first 500 feet from the shore, and he therefore abstained from giving any prominent expression to his hopes that the independence of the two walls would prove an element of stability over that difficult portion of the work. The result, however, gave to his previously somewhat vague and instinctive hopes a character of certainty, and he now pointed with confidence to the absence of bond as one of the most important features of the structure. The two diagrams (Fig. 6) might be taken to represent the bonded and unbonded sections respectively. Suppose them to be placed in such a situation that the foundation under block A yielded slightly, and that as the outside sank block C would follow it. Block D would ride on a ridge formed by the corner of block B. The outer side of block F would drop after C, and its inner side be lifted above the top of G. But the whole system D, F, and G would be balanced on the middle point of the lower bed of D, and form a kind of see-saw, hammering itself with every wave to ultimate destruction. Now trace the result of the same slight yielding of the foundation on the other section: A would drop as before, but C and F would follow it without any other disturbance of their positions than an opening of the centre joint, and a slight inclination outwards of the beds. This might take place to a considerable extent without endangering the stability of the structure. If it went too far, the block F would have to be removed, the top bed of C levelled down, and F reset at a somewhat lower level. If necessary, C might also be removed and reset; but as a matter of fact this had never been necessary. Under such circumstances as those described, and which were very ordinary ones at Kurrachee, Mr. Parkes could imagine no benefit, but much the contrary, from the insertion of block D. Another result of the presence of the block D was worthy of consideration. It had been mentioned that the two walls were liable to a rocking motion, the centre joint opening and closing to a slight extent under the influence of the swell of the sea. This motion was perfectly harmless to the structure as it stood. It involved no friction and no hammering—no injury of any kind, unless it were to the limpets in the joints. But let the block D be inserted, and what would be the effect? The friction of the tails of F and G on the top of D might prevent this harmless swaying. But if it failed to do this, if F slid on D one way and G the other, was it quite certain that they would come back again? Might not the projecting corner of D prevent this, and F slide outwards on C in preference? Such a result might well be the beginning of a most destructive action. A modification of the foregoing remarks would be applicable to the section of the

FIG. 6.



Barbados breakwater, described by Mr. Hayter. The movements would be somewhat different from those of the blocks in the bonded section in Fig. 6, but the effect of unequal settlement would still be to separate surfaces whose contact was essential to the stability of the whole. It would not be difficult, by entering into a minute examination of the effects of the wave action on the structure, to adduce other ways in which the independence of the parts was an element of stability; but the above would suffice.

He would therefore pass on to the third suggestion, that of connecting the two top blocks. No one could be more alive than he had himself been to the importance of this. He had kept it in view from the first as a supplementary design, which should be based on the results of experience as to the best mode of accomplishing the object. But the result of experience had been this, that except in certain special cases, as at the exposed end, and also near the shore, where the top blocks on the harbour side had not been locked to the course below by stone joggles, no such connection was needed. In these cases chains had been applied with good effect. Where irregular settlement had opened the centre joint, he considered it better to wait till a solid bearing was obtained before attempting to hold the blocks together, and it appeared that when this had been obtained there was no further occasion for the connection. It was a remarkable and rather unexpected result that where the bottom was uniform, however soft and yielding, the tendency was for the centre joint to close rather than to open. If it were decided at some future time, as was possible, to raise the structure to the height at which it was originally built, or perhaps rather higher, this would, no doubt, be done by forming concrete blocks *in situ*, extending over the whole width of the breakwater; but it would be useless to do this until settlement had entirely ceased.

Having felt bound to meet many of the suggestions for improvements on the plan of this work by more or less qualified negatives, he thought it right to submit his own conclusions in a somewhat more affirmative form. As at present advised, he did not anticipate any advantage on the ground of stability, economy, or rapidity of execution, from the use of blocks exceeding 30 to 35 tons. If possible, he would prefer to dispose these in such a way that each should extend across the whole width of the work, and this might be done up to the limit of 16 or 18 feet; but where a greater width was required, he would prefer two, or even three, independent walls to any kind of transverse bond. The centre joint was a weak point only in so far as two 12-feet blocks were not so stable as one 24-feet block, but in no other sense; and the weak point was not to be strengthened by bonding, nor by prematurely connecting the two walls at the top, whether by chains or by a through capping block, while the foundation remained unsound.

Gloomy forebodings had been expressed of the ultimate destruction of the breakwater. So far, however, as reasons were given for these, they appeared to be based on misapprehension. The damage was not an annually recurring event. None at all had been sustained, except what was clearly attributable to imperfectly solidified foundations; and for two years no blocks had been removed but exceptional ones from the end. Possibly a weak place might even yet be here and there found out; but he could see no way in which the work could be liable to progressive deterioration. There was no necessity to keep the expensive plant on the ground for repairs. Wherever a block was lost it was best replaced by filling soft concrete into the vacancy, and this required nothing more expensive than a barge and a few planks. It was dangerous to argue, from what an ordinary sea had done or failed to do, to what a much heavier sea might do; but with all proper reticence in this respect, he could not but think that a more minute examination of the actual effects of the sea would prove that there was still a considerable margin of stability in the Manora Breakwater.

All persons interested in sea work would feel deeply indebted to Mr. David Stevenson for his graphic and circumstantial description of the extraordinary phenomenon at Wick. Such a fact, so well authenticated, seemed almost to present the battle against the force of the waves as a hopeless one; but he would direct attention to the exceptional character of this case, and to the impossibility of ascertaining all the conditions which might have contributed to so extraordinary a result. Had this been simply the largest instance on record, standing at the head of a series of cases approaching to it by gradations, he would have been more disposed to draw general conclusions from the fact. But it seemed to stand alone. To argue from it would be to condemn as dangerous every sea barrier in existence, and to contradict the most trustworthy results of experience. In other respects Mr. Stevenson's testimony was encouraging. Mr. Parkes was glad to find him supporting the position that a high vertical sea wall with a parapet was an element of danger to the toe of the wall, and that even in such a tremendous sea as that at Wick blocks of a manageable size had been permanent at 10 feet below low water where the head of the wave could make a clean leap over the top of the work.

Representing as he did, in a certain sense, the Author of the Paper, eulogy of that gentleman would be out of place; but he could not conclude without for a moment dissociating himself from Mr. Price, for the purpose of bearing testimony to the ability with which he had conducted the works, and to the cordiality of his co-operation with himself.