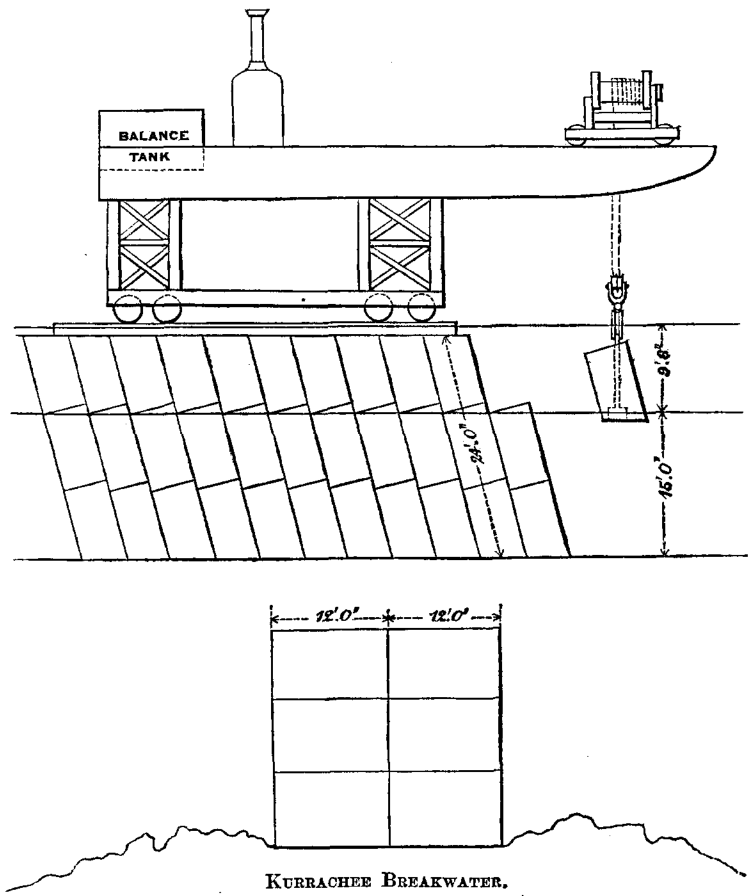
Mr. Abernethy observed that several years ago he visited the harbour works at Dublin, and was exceedingly interested in them. Mr. Stoney might be regarded as the pioneer in constructing hydraulic works with large masses of concrete. Not only had he been successful in carrying out this work, but he had shown great ingenuity in designing the requisite machinery. The latter part of the Paper contained some useful comments upon the construction of the various breakwaters of this country. On a former occasion, Sir John Coode stated[1] that one cause of the destruction of the superstructure of the breakwater at Alderney was owing to the long slope formed by the rubble mound converting the wave of oscillation into a wave of translation, and the constant percussive action of the sea upon the mound tended to destroy and to undermine the superstructure. That was the case no doubt at Alderney; and, inasmuch as the breakwaters at Holyhead and at Portland were constructed in almost precisely the same way, the only difference being that the foundations of the superstructure were more or less laid below the level of low water, he apprehended Mr. Stoney's anticipations would prove correct, and that the gradual action of the sea upon the rubble mound would convert the masses of stone into boulders, and gradually into a shingly beach. The only way to preserve those breakwaters would be, as suggested, to throw upon the seaward face large masses of concrete. He thought in future engineers should give more attention to the construction of breakwaters with vertical walls. Mr. Stoney had to a great extent solved the difficulties which had hitherto attended that mode of construction, such as the length of time occupied, and the great expense involved.

Mr. Parkes observed that the conception was a bold one, and it had been carried out with great skill. The designs were original, and almost every detail was worthy of study. The concrete mixer was an excellent contrivance, and he should prefer it to those which he had used, if it were not that the latter produced an almost perfect concrete. He had used Mr. Messent's mixer at Kurrachee, and it certainly appeared to leave nothing to be desired. Mr. Stoney's, though different, seemed to possess similar advantages. Where so much ability had been displayed, and with such great success, it might be considered ungracious to take exception to anything; but he thought it was a matter of doubt whether the principle of using very large blocks in the construction of quay walls and breakwaters should be

[1] *Ante*, p. 92.

accepted as the best. If the object simply was to build a quay wall with blocks of 350 tons weight, then the plan was no doubt a good one; but he did not think such large blocks were in most cases desirable. When no land communication existed between the place where the concrete blocks were made, and the spot in which they were to be deposited, it might be advisable to use them; otherwise he was convinced equally good results might be attained with a considerably less expenditure than this method involved. In order to show upon what this opinion was founded, he would give some particulars of the expenditure on the work connected with the breakwater at Kurrachee which had

FIG. 1.



KURRACHEE BREAKWATER.

been recently completed. The floating shears at Dublin cost £18,783. The plant at Kurrachee, which served the same purpose as the floating shears, consisted of a "Goliath" for lifting the blocks on to the trucks, which cost £660, a "Titan" setting machine, £1,975, a locomotive engine, £1,407, ten trucks of special design, £1,140,—in each case inclusive of the cost of delivery on board ship, omitting the freight,—the cost of erection on the ground was £807, and of extra heavy rails required for the unusual weight of the blocks, £300, total £6,289 as against £18,783. The blocks measured 12 feet by 8 feet by 4 feet 6 inches, and weighed 27 tons each. The next item in the list was the block wharfs, 461 feet long, which probably would contain blocks sufficient for about 350 lineal feet of wall. At Kurrachee, as there was no necessity for having deep water alongside, the block ground was a much more simple affair, and the cost of preparing it for a length of 400 lineal feet of breakwater was £3,000, effecting a saving of £1,600; so that upon those two items there was at Kurrachee a saving, as compared with the Dublin system, of £14,000 in plant. Then taking the cost of the work, the figures at Dublin were, "block standing on the wharf, including erection and maintenance of panels, casing of tubes for suspender bars, girders and masonry, £16 per lineal foot." That was precisely the same as the cost of the concrete blocks for a lineal foot of breakwater at Kurrachee, but the lineal foot contained more cubical contents at Kurrachee than at Dublin, 552 cubic feet as compared with 437, and of course if the circumstances were the same as at Dublin the section might be made the same. The cost at Kurrachee for concrete per cubic yard was 15*s.*; at Dublin it was 21*s.* Probably the difference was to some extent due to the facing of masonry, which no doubt there had been good reason for adopting. Then Mr. Stoney was obliged to introduce into the large blocks two cast-iron girders of 11 cwt. each, in order to take the bearing of the suspending bars, and that would add about £1 per lineal foot to the cost of the wall. The same end was served at Kurrachee by a couple of pieces of hard wood, which had answered every purpose for lifting the smaller blocks. The wood came to 3*s.* per block, or 4*s.* per lineal foot of breakwater, so that upon that score there was a saving of 16*s.* per lineal foot. This seemed a small matter, but it was important in considering the next item. The cost of lifting and setting a block, including maintenance of floating shears, was £2 10*s.* per lineal foot, making, with the 16*s.* remaining over from the last item, £3 6*s.* Now the actual cost of setting the blocks at Kurrachee per lineal foot was £3 9*s.*, giving an advantage of 3*s.* per lineal foot to the Dublin plan, but that advantage was gained by an extra first cost in plant of £14,000, and would be more than balanced by putting in a portion of another item, the parallel of which at Kurrachee was included in the £3 9*s.*—"shifting the moorings, maintenance of wharf, and sundries, £1." There was no such item at Kurrachee, and a portion of that ought to be added to the £2 10*s.* The item of 10*s.* for "filling side grooves with concrete" was omitted as not being applicable to breakwater work. It was, therefore, evident, even without taking into consideration the extra cost of work of this kind in India over what it would be in Dublin, that there was no advantage in the use of these very large blocks, but that there was the positive disadvantage of a much larger expenditure in the first cost of the plant. With regard to the question of rapidity of execution, he also thought no advantage was to be gained by the use of such large blocks, except possibly where land communication could not be had. Each block at Kurrachee weighed 27 tons, and represented about 9 inches length of breakwater. During the four months, November, December 1872, January and February 1873, a length of 710 feet of breakwater was constructed. In that time there was probably less interruption than there would be in England during any four months of the year, but they were the only four months during which operations could be advantageously carried on there. The actual work done in an uninterrupted day, taking the average of three months when there was no material interruption in any way, was ten blocks, and he believed that that rate could be maintained. Ten blocks per day represented 7½ lineal feet of breakwater; and on the basis of two hundred working days in the year, that would give 1,500 feet per annum; but the Author only claimed from 1,000 feet to 1,200 feet as what could be done upon his system. Probably the higher estimate might be safely adopted, and Mr. Parkes would not have questioned one still higher. He might state, however, that the rate of ten blocks per day was by no means the limit of the capacity of the "Titan," for nineteen blocks had been set in one day, and on one occasion six blocks in an hour and forty minutes, being at the rate of thirty-six blocks in a day of ten hours. Delay was always caused either by the diving work or by the blocks not being brought up fast enough, both of which operations might be accelerated by an increase of force. At low tide the depth of water was 15 feet. He believed that 1,500 feet per annum was within the mark, and that when the staff got into full work the rate would be greater, for every year at Kurrachee the rate had materially increased. The plant used at Kurrachee was only applicable where there was land communication, but the places in which such communication could not be obtained were few. Detached breakwaters had from time to time been proposed, but such schemes were seldom carried out, as breakwaters starting from the shore were generally preferred. Where, however, water communication was the only one possible, it was probable that a plan like the Author's, with, possibly, some modification of the mode of attaching the block when it had to be carried out to the sea into rather troubled water, might be advantageously employed. At Suez the quay walls were built of blocks nearly of the same size as those at Kurrachee. They were carried to their place on barges, but the rate of work was considerably slower than at Kurrachee. It was impossible to make a satisfactory comparison between the foundation in Dublin harbour and that at Kurrachee. At the latter place the bottom was sandy from 25 feet to 30 feet below low water, in the part to which he had been referring. Rubble stone was dropped from boats, and was levelled by divers. The cost of levelling was about 23*s.* per lineal foot, where the work was carried out as it ought to be. Nearer the shore, where an excess of stone was thrown in, and the amount of excavation was greater, it was more expensive, and in one season was £2 15*s.* per lineal foot. In that case the work was assisted by the steam dredger, which excavated a trench for the blocks. The bottom of this trench was afterwards levelled by divers. In some parts the trench was nearly 6 feet deep; but this was more than he had intended. The cost for excavation in Dublin Harbour was £3. He hoped some explanation would be given of that item, for, considering the excellent contrivance for getting at the bottom, he imagined it might have been done at a cheaper rate; but as he was not acquainted with the circumstances, he did not feel justified in saying the cost was greater than it ought to have been.

Mr. C. B. Lane considered Mr. Stoney's invention a stride in the direction of the economical construction of engineering works in deep water. He would confine his observations to bridge piers. The introduction would doubtless be recollected of Dr. Potts' pneumatic principle for sinking cylinders, and the ingenious reversal of that principle so effectually applied at Rochester bridge; and finally the modifications which the centre pier of Saltash bridge was constructed at a depth of nearly 100 feet. He thought, however, when the necessity arose for similar structures, Mr. Stoney's principle would be found applicable in analogous conditions with great economy. He had the pleasure of visiting these works a couple of years ago, and could assure Mr. Parkes that "land carriage" was inapplicable at Dublin.

Mr. VERNON HARCOURT observed, through the Secretary, that he had been much interested in the description of a work in which the appliances and method of construction were so admirably adapted for carrying out the projected design, and in which great solidity and durability had been attained at a comparatively moderate cost. The Author had referred to the applicability of this system of building with large blocks of concrete to the construction of piers and breakwaters. Mr. Harcourt considered the system might be adopted with advantage in the case of large works, especially in localities where stone was scarce, or when it was requisite to have a road on the structure. No staging would be required, and thus one source of sea damage would be avoided, a solid mass, immovable by the sea, being deposited at one operation. The extremity of the work could also be easily secured by a cross wall of huge blocks, and all chance of injury from unequal settlement would be removed. It was probable that the rate of progress would be greater than the ordinary methods admitted of, as less time ought to be employed in depositing one large block than a number of smaller ones; but he considered the Author was too sanguine in the estimate of the number of possible working days in exposed situations. Though the blocks could be deposited on any one calm day in winter, it would be impossible to proceed with the works in the winter months, as the process of levelling the bottom must be carried out, whether the foundations rested on a rubble mound or on the natural bottom; and even in the summer months there would be many days on which the work of levelling the bottom and depositing blocks could not be attempted. The employment of a diving bell, for the purpose of levelling the bottom, would probably be found inexpedient in exposed situations where there were strong currents. Diving bells had, in the first instance, been made use of at the Alderney Harbour Works; but when the bell was lifted a little off the bottom, the rapid tidal current drove the men against the sides, so that the use of the bell had to be discontinued, and helmet divers exclusively employed. He considered that equal care should be taken to place the blocks close together in a breakwater as in the work described, for the slightest aperture between them would expose their sides to the action of the sea, which, in time, would wear a passage through, and affect the durability of the work.

In carrying out comparatively small works this method would not be advisable, owing to the expense of the requisite plant, and to the necessity, in addition, on the sea coast, of constructing some place of shelter for the barges. A work on which he was at present engaged, the construction of a harbour at Rosslare, near Wexford, could be most expeditiously executed with the appliances described, as the design consisted of a viaduct, 1,000 feet long, supported on twenty-four concrete piers, the largest of which would only weigh about 220 tons, from which a solid breakwater, 1,000 feet long, was to extend into about 21 feet depth of water, composed of two concrete walls with filling between. The cost, however, of the plant for building with large blocks, and of making a place of shelter for the barges, would swallow up nearly half the capital proposed to be expended. The same objection would apply to most piers and harbours made for trading purposes. In the work just referred to, a similar result, namely, constructing each pier in one block, had been attempted, with scarcely any plant, by depositing concrete *in situ;* but this, though partially successful, had proved, unlike the Author's method, a slow process, as several consecutive days of calm weather were required for erecting the casing and depositing the concrete; and one day of windy weather, from an exposed quarter, damaged the casing, and necessitated the recommencement of the work. Moreover, this system involved a large expenditure of cement, and, unless the casing was carefully closed in at the bottom, an eroding action was liable to occur close to the foundation, tending to undermine the block. With extreme care and ample time, a breakwater might probably be constructed, in shallow water, in one solid mass throughout, by the process of depositing concrete *in situ*, which might compare favourably as to durability with any other system of construction. He considered, however, that in constructing an upright breakwater of concrete, with a moderate outlay on plant, the methods adopted at Aberdeen and at Kurrachee were the most suitable, though to lay down any fixed rules for the construction of marine works would be unwise, considering the varying circumstances under which they had to be carried out. The Author had referred to one instance in which the stone forming the rubble mound of a breakwater tended to travel towards the land. Exactly the same movement occurred at Alderney, where the smaller rounded stones on the surface of the mound were carried towards the shore extremity of the breakwater, and some ultimately round Grosnez Head into the adjoining bay; this result being due to the set of the tide, and the direction of the strongest wind. The wearing action of the sea was not confined to rounding the foreshore stones, but, where the foreshore was high, the face stones on the seaside of the superstructure, though composed of granite and of the equally hard native Mannez stone, were rounded and almost polished by the constant attrition of the foreshore.

Mr. STONEY said that last year a length of 411 feet of quay wall had been finished. The rate of progress depended almost entirely upon the diving-bell. If there were two diving-bells, the building could go on twice as rapidly as at present. On the previous day a block had been lifted and put down in the afternoon, and the same could be done day after day in a sheltered harbour. In addition to the 411 feet of quay wall completed last year, four large blocks of 140 tons each had been constructed. Two of these were slung together and conveyed 3 miles down the river in December last, and two more a fortnight since. These were for the purpose of protecting a breakwater on the south side of the harbour. The foreshore there was formerly constructed of large blocks of granite weighing from 6 tons downwards, which had been to a great extent comminuted and gradually washed away. Before 1862 there was an annual expenditure of £600 for replacing the foreshore. He accordingly replaced the material washed away by large blocks of 50 tons weight, the cost of which was about £3,000. This protection lasted twelve years, and the annual expenditure of £600 (or what at the present rate of wages would be represented by £900) was saved. One of these blocks, in the winter of 1873, was moved to a distance of 30 feet and turned upside down. He was now putting down 140-ton blocks in order that they might not be displaced. He had stated that the blocks described in the Paper were of 350 tons weight, but he had reason to believe that they were more. The displacement of the floating shears was a little over 7 inches for each 100 tons; and when the block was suspended, and water poured into the tank, the shears went down 54 inches, which would give a weight of nearer 400 tons than 350 tons. Last autumn he had constructed a beacon-tower similar to that described in the Paper, which was carried down with equal success. It weighed a little over 80 tons. It was placed *in situ* and formed its own cofferdam. He might add that, after the floating shears and diving-bell had been contracted for, and to a great extent completed, some of the members of the Ballast Board thought it desirable, in undertaking a work of such a novel character, to obtain the countenance of some additional authority to support them. They accordingly permitted him to consult Mr. Bateman, whose report on the matter in 1865 was too flattering for him to repeat; but it was a great encouragement in carrying out so novel and arduous an undertaking.

Mr. PARKES, in answer to a question why he had adopted the peculiar form of laying the blocks at Kurrachee, said that the origin of the idea was that of vertical courses, but that would have been practically impossible, because the end course would be liable to topple over seawards, especially when a weight was brought upon it. For that reason they were laid slanting backwards, about 3 inches in the foot. The great object in sea-work was that each block should rest upon a single block below, and have no break of joint. When one block rested upon two, if the foundation was not perfectly solid, there might be an uneven settlement, and then the upper block would rest upon a mere hump, and would rock backwards and forwards. The system, moreover, was found by experience to be rapid in execution, as each block when lowered was guided by the inclined face of the block behind it into its place, and at once took a fair bearing.

SIR JOHN HAWKSHAW, Past President, said, he had great pleasure in bearing testimony to the successful mode in which Mr. Stoney had carried out works of a novel and interesting character. About six months ago he had the pleasure of seeing them, and the whole operation appeared to be managed with extraordinary ability. For the situation, he thought the system a successful and appropriate one; but he could not agree that the method was equally applicable to breakwaters generally. This was an instance of generalising from a particular structure, and concluding that it was the best for all possible occasions. Engineering was not so simple as that would seem to indicate. No plan could be laid down which would be everywhere applicable. It was necessary to consider the special circumstances of each case, the material to be dealt with, and the situation where the works were to be carried on. In many instances it would be impossible to apply this method of setting large blocks. He had such cases under his own supervision at the present moment. On the coast of Holland, for instance, the surf was too high to admit going out to sea with such an apparatus during a sufficient number of days in the year. Nor could such a plan be adopted at Holyhead. The reason why the Author had been so successful was, that he was building in a sheltered place, which was practically an inclosed pool. He was inclined to think with Mr. Parkes that there were cases in which the method adopted at Kurrachee would be better. There were also other cases in which even the mounds that it was suggested were only put down to be ultimately destroyed might be adopted with advantage. At Holyhead, for instance, there was a mountain close at hand to obtain stone from at little cost. At Alderney and at Portland also the mound had been used, because the stone was close at hand, and could easily be thrown into the sea in large quantities, and at comparatively small cost. No doubt these mounds might to some small extent wear away in the course of time; but he knew of no work done by engineers which could be regarded as everlasting. Although a solid wall faced with granite was a more durable structure than a mound of stone on which the sea dashed, and which was liable to be worn away by attrition, unfortunately the cost was vastly greater. The breakwater at Holyhead, which had a central wall, an interior quay wall, and a wide esplanade, cost about £163 per lineal foot, while that at Dover, which had a vertical wall of less average height (51 feet as compared with 66) had cost £345 per lineal foot. Taking the difference of cost, and setting it aside as capital upon which interest was saved, the possible repairs referred to by Mr. Stoney would become a mere bagatelle. By effecting a saving of £300,000 or £400,000 outlay, there was an annual saving of £20,000 a year, and an expenditure of, say £2,000 a year in keeping the structure intact would be trifling in comparison. It was necessary to build a vertical wall at Dover to provide deep-water berths for steamers, but at places like Holyhead, Portland, or Alderney, this method could not be adopted with advantage.

Sir John Coode agreed with Sir John Hawkshaw, both in his admiration of the arrangements made by the Author, and with regard to the impossibility of adopting any plan which should be of universal application. The arrangement of the floating shears was admirably suited to the particular circumstances of the River Liffey. Before making any further remarks, he should be glad to know the number of cubic feet to a ton in the blocks of stone which the Author had built. [Mr. Stoney said he had calculated 14 cubic feet to the ton.] In that case the stone must be remarkably dense. He had himself built blocks of a similar description made with stone of a Silurian character, and their weight was 15·33 cubic feet per ton. With regard to the mode in which the hearting was composed, it was, no doubt, an admirable one for blocks of that character. It was adopted about the same time in some works with which he was professionally connected, at Table Bay, by Mr. A. T. Andrews, M. Inst. C.E., the Resident Engineer, and had proved most successful. This mode of forming the blocks was not adopted for the first time at Dublin. The same method had been employed at Alderney twenty years ago, as was also the ingenious method of lifting the blocks by T-headed suspended bars. He had greatly admired and used it as being one of the simplest contrivances yet adopted. It was, however, desirable to have a mode of freeing the lewises from the block by some self-acting arrangement which could be worked from the surface of the water, and he thought that would be shortly accomplished. The diving cylinder was an ingenious arrangement, and, no doubt, most suitable to the particular work in question. Curiously enough, an almost identical bell was made in the same year for the work at Table Bay, and was successfully employed by Mr. Andrews. Great credit was due to the Author and his foremen for the remarkable accuracy with which the work had been put together. The cost of the wall was stated to be £40 per lineal foot, but that did not appear to include the first cost of the plant which, in such a work, was a material item. In the case of a wall 1,000 feet long it would add £33 per lineal foot; and in the case of a wall 3,000 feet long the additional cost would be £11 per lineal foot. The cost of the bell work, including maintenance, but not interest on the plant, was said to be about 15*s.* per cubic yard of excavation. That, again, did not include the first cost of the plant. Taking into consideration the large quantity of excavation required, the cost of the plant would in this case add 5*s.* per cubic yard, making the amount 20*s.* It might be objected that it was not fair to take the whole cost of the plant, because it would be of some value when the work was completed. His own experience was no one knew how to use special plant when the particular work was finished. But taking only half the cost of the plant, the 15*s.* was increased to 17*s.* 6*d.* He had excavated large quantities of rock by means of the diving helmet, without the bell, and the cost, including the contractor's profit, varied from 14*s.* 8½*d.* to about 16*s.* In many cases, too, the helmet divers could work when, owing to the agitation of the water, it would be impossible to use the apparatus. That showed that an arrangement which might be very suitable for quiet water like the Liffey, was not economical, or indeed applicable in a sea-way. It had been assumed that if the shears were used for a breakwater only two hundred days in the year a certain amount of work could be done; but it would be a mistake to expect anything like two hundred days' work in the open sea-way. From forty to fifty days, he thought, would be nearer the mark. It was stated in the Paper that works of rubble contained the elements of their own destruction; and the Author said, properly enough, that if the slopes were paved and the structures protected—that was, if proper and reasonable precautions were used—there was nothing to be apprehended. Reference had been made to several places where material had been swept round the pier-heads and formed dangerous shoals. He was not aware that that had happened to such an extent, and would be glad of the particulars. The Author further stated that, in the case of a vertical wall, if the foundations were secure, and if the stones were massive enough—so bonded together that they could not be destroyed by the action of storms—it would possess the required elements of stability. Granting those assumptions, of course the result could not be denied. In the latter part of the Paper, only one hundred and fifty days' work per annum had been calculated upon; but even that was far too great. One material point appeared to be lost sight of—the effect of the tidal currents. In projecting a work across a bay, the current would necessarily be more or less increased; and to put down two blocks, one over the other, in such a tide-way would, he thought, be a formidable undertaking. It had been stated that Mr. Stoney might be considered as the great pioneer in the construction of hydraulic works in concrete; but he was not entitled to that distinction. "*Palmam qui meruit ferat.*" He believed the credit was due, not to English or to Irish Engineers, but to the French, who had adopted the system of concrete blocks thirty years ago at Algiers. It had likewise been said that the Holyhead and the Portland breakwaters were constructed in almost precisely the same way as that at Alderney. There were, however, material differences between the two first and the last-named structures. He agreed that the plant for blocks, however applicable to large works such as those at Dublin, would be out of place in smaller works. With regard to the mode adopted at Kurrachee, the same system was recommended by Major Askwith, of the Royal Engineers, to the Committee for the construction of a harbour of refuge in Dover Bay, in 1846, and great credit was due to that officer for suggesting that mode of construction. He hoped Mr. Stoney would receive his criticisms in the spirit in which they were made. If their discussions ceased to be critical they would cease to be profitable.

Dr. Pole stated, in corroboration of Sir John Coode's remark as to the early use of concrete for sea works by the French, that he had occasion some twenty years ago to examine, in conjunction with the late Mr. Rendel, the great harbour and dock works then being constructed at Marseilles, and found that concrete was used there on a large scale. Not only were concrete blocks of great size formed on shore and laid in the breakwater, but, by a most ingenious mode, the same material was deposited in a loose state under water, at a considerable depth, to form quay walls, and the structures thus built were found to have great stability.

Mr. Bateman, Vice-President, said when called upon to advise the Dublin Harbour Board he felt he had a difficult task. He had some hesitation in criticising Mr. Stoney, who, he was quite sure, was better able to instruct him. Mr. Stoney laid before him the whole of the designs, and showed him the results of the experiments made upon concrete blocks, which had been continued for many years. He went through all the calculations, for the purpose of forming a correct opinion upon the proposed work, and he felt constrained in every way to recommend the adoption of the proposed plans, which, he was happy to think, were now drawing to a successful completion. Great credit was due to Mr. Stoney. Other persons had, no doubt, used large concrete blocks, but the Author was entitled to the credit of constructing blocks of anything like 400 tons weight. The blocks referred to at Marseilles weighed only from 13 tons to 16 tons, and their size was 4 feet by 4 feet by 12 feet, or thereabouts. The harbour at Marseilles was a beautiful structure. It was formed entirely by a long mole of concrete blocks cutting off a portion of the Mediterranean from the general sea, within which the docks existed. The concrete blocks were formed, in a somewhat rude manner, of large gravel and hydraulic lime, and were tumbled in at random. They formed a protection one to another by resting upon and jamming each other fast. He did not believe that the sea, although it broke with considerable force against the breakwater, would move any of the blocks. Upon these blocks was raised a heavy parapet wall, which protected the docks from the sea, within which were offices, buildings, a wide roadway or esplanade, and a quay wall. If they were isolated blocks, they would be liable to be moved in a different manner. He agreed in the opinion that every work must be considered with reference to its peculiar circumstances. At Holyhead, Portland, and other places, where there was a large mass of rock behind, although a breakwater was constructed which carried with it the elements of its own destruction, yet that gradual waste might be repaired at a less cost than the interest of the money that would be required to make an indestructible work. It often happened that a cheap construction would encourage the establishment and extension of trade in a manner which would enable the same place afterwards to construct a better work of more suitable material. Where, however, as in Dublin, there was a river crowded with vessels, in which it would be extremely inconvenient to have a cofferdam, and where the trade was constantly increasing, it was a matter of importance to be able to construct a wall which should not, during its construction, encroach in any way upon the water. That arrangement had been successfully carried out. When he examined the plans he was aware that blocks of 80 tons had been carried into the open sea. It now appeared that two blocks of 140 tons each had been conveyed by the same vessel, and placed in the open sea, in a manner that would probably defy the force of the water, which had previously moved a block of 50 tons. It was astonishing that such a force should be exerted by the water in that situation, and it showed that isolated blocks could scarcely be made too heavy. The experience gained by these arrangements might be usefully applied in many parts of the world. He did not wish to discuss the details of the work, but he should be glad to hear from gentlemen having special experience, any defence of the particular structures which the Author had attacked. It was a sign of the advance of engineering knowledge that blocks of 350 or 400 tons could now be constructed and laid.

Mr. W. Dyce Cay thought the barge unsuitable for building breakwaters, as a slight ground swell or rolling motion would make the setting of large blocks with it a difficult and dangerous operation. He agreed as to the propriety of building breakwaters with blocks of very large size, but the expense of manufacturing them in a blockyard, and carrying them out to the work when solidified, was a great disadvantage. He wished to suggest another method by which, while the advantage of building with large masses was retained, only small weights required to be transported, namely, by building with concrete deposited *in situ* inclosed in large bags. He had deposited a number of bags containing each 100 tons of concrete in the construction of the new breakwater at Aberdeen. These bags were deposited to form an apron along the exposed side of the work. The plant which he would recommend in general for the purpose of depositing bags would be similar to that he had used for depositing bags containing 16 tons of concrete each. This was done by means of a wrought-iron box or skip, the bottom of which opened on hinges like the bottom of a hopper. Into this box was fitted a bag, which was filled with the required weight of concrete, and was then sewn up. The box with its contents, viz., the liquid concrete sewn up in a bag, was lowered by the cranes to the divers, who by signals guided it into position close above the required site of the bag in the work; a trigger was then pulled, which released the bottom of the box, and the bag was deposited. The whole of the foundations of the Aberdeen breakwater were constructed in that manner. The system possessed great advantages in point of economy and solidity of work, as the expense of the manufacture and transport of heavy blocks was avoided. The accurate levelling of the foundations was also unnecessary, and when deposited the soft bags lay so close to one another, that an almost monolithic mass was obtained. He thought the method applicable to the building of the whole of the submarine part of a breakwater, except perhaps the part just at low water level, where special precautions would have to be taken to prevent the wash of the sea from tearing the bag before the concrete was sufficiently set.

Mr. J. I. Thornycroft said the Author's method had been objected to on the ground of expense. He was indebted to Mr. Rich for an idea which would greatly lessen the cost of the shears for lifting the blocks. It consisted in dispensing with the centre part of the float, which served no useful purpose, but rendered necessary great longitudinal strength. There were several objections to the shears employed. Their stability was dependent on staying the block in the centre of the line of the vessel. It appeared to him that the shears ought to be constructed with the centre of buoyancy as near as possible to the block to be supported; in that way the great balance weight required by the existing shears would be avoided. If the vessel supporting the block were divided into two parts, one alongside the wall being built, and the other also parallel to the wall, but say about four times as far from the centre of the first part as the mass to be carried was from it on the opposite side, the frames of the shears in side elevation would be a simple triangle, shear legs forming a strut down to the supporting float, a strut also to the counter weight, and a tie from this point to the top of the first strut or shears. The barge at the back or second part might contain all the machinery and the heavy parts, and thus the necessity for ballast might almost be avoided. So far as the water in the tank was below the level of the surrounding water, it was supported by the surrounding water, and that part of it, therefore, was almost useless, in fact it added unnecessary bulk, for the water was not carried by the shear legs over it, as appeared to be conveyed in the Paper. By the plan proposed the shears might be greatly reduced in size, and therefore might be more cheaply constructed;

and much greater stability would be obtained. It had been stated that in raising the blocks the entire weight was not lifted by hauling in the chain, but by filling the tank with water, and in that way the strain was equal on every strand of that chain round the blocks. The Author had not remarked, however, that this was not the case in lowering the block, where there would be more strain on the end made fast than on the other end. With regard to the use of the two pairs of tackle to lift the blocks, it appeared to him that one tackle was in danger of getting nearly the entire load.

Mr. REDMAN said there was some analogy between the Paper under discussion and that read last session by Mr. Milroy,[1] the problem being somewhat similar, to obtain a foundation for a quay wall in a considerable depth of water, without the intervention of a cofferdam. The expedient was certainly a bold one; and he thought the talent and ingenuity displayed in working out the details, in what might almost be termed river engineering, would enable the Author to overcome many of the practical objections raised to the application of the system to submarine structures. It was undoubtedly impossible to apply any fixed rule or classification to harbours. He had attempted to classify lighthouses, but he found great difficulty in doing so, and it was the same with breakwaters and harbours. In the discussion on the Alderney breakwater he had pointed out the great variety existing in the conditions surrounding the national harbours of the country.[2] What appeared to be an exceedingly bold experiment on the shores of the Liffey would be still more hazardous at Plymouth, Cherbourg, or Alderney. Taking the dimensions given by the Author, the weight of each block, according to Mr. Redman's estimate of the material, would be about 312 tons instead of 350 tons. Some interesting information had been furnished with reference to the breakwater at Kurrachee. Any one intimately acquainted with the harbour of Alderney, with its rocky bed 20 fathoms deep, a precipitous shore, and an offing across the Atlantic, would hardly say that a system applied at the head of the Arabian Sea for a long and gradually shelving foreshore, would be applicable there. No analogy existed between the two cases. There was also a liability to error by a comparison of the prices at the shores of the Liffey and at the outlet of the Indus. It appeared, however, that the suggestions contained

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxv., p. 186.

[2] *Ante*, p. 84.

in the Paper were as applicable to a place like Kurrachee as anywhere. If the machinery at Kurrachee were amplified and the blocks made larger, the horizontal cross-joints in the structure would be done away with; and if the blocks were of the entire width of the work, the longitudinal vertical joints might also be done away with, and the action of the water through the work to a certain extent checked. It would be objectionable in many structures to have the water pouring over the top. The settlement that occurred at Kurrachee with entire blocks would be less liable to produce dislocation of the superstructural mass. Any attempt to reduce the cost of the great national breakwaters was worthy of encouragement. A Royal Commission had been sitting upon unseaworthy ships, and the public mind was quite alive to the expediency of the inquiry. It was looked upon as criminal to send vessels to sea that were not thoroughly seaworthy, and the public might hereafter see the necessity for greater protection to seaworthy ships.

Mr. A. T. ANDREWS remarked that twenty years ago, when engaged in some repairs in the West India Docks, he made large blocks of concrete, of which one-fourth consisted of Kentish rag, which answered very well. In carrying out works at the Cape of Good Hope he had used large blocks in building dock-walls. The funds at his disposal were limited, and he had to employ unskilled Kaffir convict labourers, who, however, in a short time became skilful in constructing concrete walls with large stones. The stones were hard and dense, about 12½ cubic feet to the ton, and no tool could touch them. A bed of moist concrete was made, and the stones were worked into it. The weight of the blocks was from 10 tons to 12 tons. Some heavy walls 40 feet high were built of that material, and the structure was very cheap, considering that the cement had to be imported from England. He had employed the same system of large blocks in order to protect the end of the breakwater. Their weight was about 70 tons, and they were laid just above low water. The sea gradually took them down a slope, and as they moved others were put behind. With the aid of convict labour the cost was from 12*s.* to 18*s.* per cubic yard. Although the labour was free, the cost of superintendence was considerable, so that the expense of labour was not all saved. There was also a large outlay for tools for the convicts.

Mr. J. N. DOUGLASS said it had been stated by the Author that blocks weighing 50 or 60 tons had been moved by the sea in the Bay of Dublin. Unfortunately, there appeared to be no reliable information as to the maximum weight of blocks of stone capable of being moved by the sea. Such information was, in his opinion, a matter of great importance in the construction of breakwaters. The heaviest seas he had experienced were on the west coast of England, about the Land's End, and the Scilly Islands. In the latter place a piece of rock had been moved weighing over 200 tons, and that not in the most exposed situation. He should expect that in the most exposed part of the coast a block of 300 tons might be disturbed by the heaviest seas. He believed that Mr. Stoney had acted judiciously in adopting blocks of 350 tons, and he agreed with him in the use of such blocks in vertical walls for breakwaters. At the same time he concurred in the views as to the difficulties attending the transporting and placing of such blocks in sea works with the floating appliances used so successfully in the smooth waters of the Liffey. He thought the number of days in which blocks could be safely transported and set in this manner would not approach one hundred and fifty per annum; indeed, in some places where breakwaters were most required, he should consider thirty to forty days, including Sundays, as many as could be relied on. Besides the uncertainty of obtaining smooth water, there would be the further difficulty experienced in mooring the craft, and setting the blocks in the strong tide generally met with at the end of a breakwater carried out from the shore. He should prefer transporting the blocks by land somewhat in the manner adopted at Kurrachee. In that case the blocks were only of 27 tons weight; but heavier machinery of the same description might be successfully adopted. He was of opinion that, with the blocks transported and set in this manner, the work would be carried on with greater regularity, expedition, and economy than by any floating appliances. Large blocks had been used for many years in vertical walls by French engineers, and the blocks had been transported and set in the work by barges, but this was in smooth water as at Dublin. In 1868 he visited Brest, and went over the works of the Port Napoléon, then in progress, where blocks of 150 to 200 tons weight were transported and set in the vertical walls of the work by barges; these works were, however, in sheltered water, and there was little or no tide. The blocks were formed of small rubble in London Portland cement. They were built above the level of high water on trollies, and when ready for the work they were sent down an incline to the level of low water, and the barge or barges were secured to them with the rising tide. They were then transported to the intended site, and placed in position with the following ebb-tide. He was of opinion that in such a work as that at Brest the admirable floating shears and appliances of Mr. Stoney might be used with success.

Mr. STONEY said he had tested the weight of the blocks by building a smaller block of similar texture, and weighing it on a table. The blocks were composed of rubble, not of concrete. A visit to the works would enable a convincing proof to be given that the blocks were more than 350 tons in weight. The horizontal area of the floating shears was within 7 feet of 6,000 square feet, and the barge went down 54 inches into the water when the block was at one end and the water pumped into the other to balance it. The block, however, was heavier than that would indicate, because when first brought alongside the wharf, the tank end of the shears was considerably deeper in the water than the bow end: there was a difference of 4 or 5 feet; and that, he thought, could not represent less than 30 or 40 tons. Of course, moorings were necessary to hold the vessel in position. When the four blocks of 140 tons were put down, the moorings were laid down the day before where the current was running from 2 to 3 knots an hour. He did not apprehend any difficulty in connection with the current, except that a more powerful tug might be required. What he did fear, however, was the waves; and, as far as his limited experience went in connection with breakwater work, he thought that on those days when the waves exceeded 3 feet in height it was not desirable to use the methods he had adopted. Such waves had occurred when he laid the blocks in December. Two of the blocks were recently deposited immediately before a severe gale broke over the coast of Ireland. It was almost superfluous to remark that he never claimed to be the pioneer in the use of concrete. The merest tyro was aware that concrete was adopted by the French for breakwaters long anterior to its use in England, and he believed it was employed by the Romans long before it was used by the French. An objection had been made to a statement in the Paper that the vertical breakwater would be secure if the individual stones were massive enough, or were so bonded together that they could not be disturbed by the action of storms. But one of the ways in which vertical walls failed was by the reflex action of the waves or impounded air driving out individual stones; and he submitted that blocks of from 300 to 400 tons weight would not be liable to this source of failure. The first notice he had seen of Sir John Coode's diving-cylinder was in Humber's work on "Modern Engineering,"[1] published in 1868, some years after his own construction had been made. But both Sir John Coode and he had been anticipated by a Frenchman, who took out a patent in 1858 for a similar contrivance, which he discovered after his designs were completed. He believed, however, that this machine was the first instance of a chamber 20 feet square; and it had this advantage over other diving appliances, it afforded a plane surface of 400 square feet which was perfectly calm in rough weather or in currents, and enabled the bottom to be levelled with a degree of accuracy attainable by no other method. If, for example, there was 1 inch in depth of water at one corner of the bell, and ½ inch in the opposite corner, this showed that the bottom required to be excavated ½ inch in the latter to bring it to a horizontal bed. With regard to the cost of the plant, it had been overlooked that he had charged 7 per cent. interest, which would repay the whole amount with interest in twenty-four years. The present works were of great extent; after they were completed others would probably be required. He thought the diving-bell would be useful in harbours for various purposes, such as drawing stumps of piles, or removing rocks and large stones. The block wharf was designed to act as a cofferdam for future graving docks to be constructed inside it, or as a wharf for vessels to berth alongside when not required for building purposes. In considering the question of cost, it should not be forgotten that the wages of all classes of labour had risen enormously within the last few years. He had been asked to refer to cases in which shoals had formed inside harbours. One of these was at Howth, where a shoal, formed a few years ago, was believed to have been produced by débris from the foreshore. A similar occurrence was slowly taking place at Kingstown, where Mr. Barry Gibbons, late Engineer of the Board of Works, had constructed a groin, to prevent the stones from travelling into the mouth of the harbour. The groin was carried away by the action of the waves, and there was no doubt a slow movement of the stones round the pier head and into the harbour. A few years ago he saw a deep valley in the foreshore of the Holyhead breakwater, extending to near low-water level, and a stone wave reaching to near the top of the parapet. Last autumn that stone wave was moved, and he saw that it was much nearer to the end of the pier. The stones

[1] *Vide* "Record of the Progress of Modern Engineering," 1866. By William Humber, Assoc. Inst. C.E., p. 45.

forming the foreshore were nearly all rounded, like an ordinary sea beach, showing the action of attrition. Mr. Vernon Harcourt considered it possible that the diving-bell might not be suitable in currents, because the divers would be swept away. They would not, however, require to work exposed; indeed they were not wet farther up than the ankles, as they never went below the diving-bell, which rested on the bottom. They excavated inside, and when it was lifted off the bottom they sat on benches and were moved along with it. It had been suggested that the mode of construction adopted at Kurrachee was suitable for quay walls; but he was not of that opinion. A "Titan," such as that used at Kurrachee, could not be placed on the top of a quay wall, for the width of the latter at high water level did not exceed 6 feet, which was less than the gauge of the railway on which a "Titan" travelled. In addition to this, the rough surface of concrete blocks, such as those used at Kurrachee, would be totally unfit for ocean ships to lie against in a tidal river where ashlar masonry or fenders were necessary to give the shipping a fair surface to bear against. Besides, the trade of Dublin was extending so fast that it was a great advantage, as soon as 1 foot of quay was completed, to be able to make it available for shipping. That could not be accomplished if a "Titan" were employed in the way described. There was no place for a service ground at the commencement of the new quay, because the existing quays came up to it and were, as well as it, completely occupied with vessels. It had been suggested that the cost of concrete was excessive; and a comparison had been made between its cost in Dublin and that at Kurrachee; but comparisons of prices were apt to be fallacious. The present price of the best Portland cement in London was from 45*s.* to 55*s.* per ton, free on board. The cost of the casks to export it to India was 20*s.* each; the freight was 40*s.*; making collectively 5*l.* 10*s.*, to which was to be added the cost of primage, landing and storing, making in all 5*l.* 15*s.* If the proportions were the same as in Dublin, it would take 19*s.* 2*d.* worth of cement alone per cubic yard of concrete, without taking into consideration the cost of ballast and labour. It was obvious, therefore, that the same result could not now be obtained for 15*s.* The system adopted at Kurrachee commanded great admiration for the purpose for which it was used, but there were certain features connected with it that rendered it not so desirable as might be supposed. In a report by Mr. Parkes in 1872, that gentleman stated that 6 per cent. of the blocks then laid had to be taken up and reset; that one block on the harbour side was driven out by the force of the sea, and that "after the monsoon it was found that the last block on the sea side had fallen back about 9 inches from the line of that on the harbour side, and this continued, though gradually decreasing in amount, to near the shore. The slight movement of the blocks among themselves had rubbed off some of the little inequalities which had prevented adjoining surfaces from fitting quite closely when first laid, and so enabled each block to fall back upon the one behind it to an infinitesimal extent in any one case, but amounting in the aggregate to 9 inches." . . . . "The motion of the blocks under the influence of a very moderate swell was clearly discernible after the monsoon. The joint along the centre of the breakwater was seen to open and close with every wave to the extent of $\frac{1}{4}$ of an inch, at a spot immediately over one of the projecting masses of rock in the foundation on which the blocks seemed to hang as on a pivot."[1] Mr. Parkes attributed these movements to the existence of irregular foundations which yielded unequally after the blocks had been laid; but, whatever their cause, he thought they were not calculated to promote the longevity of a breakwater. In place of thirteen or fourteen blocks of 27 tons, one large block on such an uncertain foundation would not have presented the longitudinal joint described, opening and closing by the swell of the sea; nor would there be any such attrition between block and block. Mr. Parkes had also instituted a comparison between the cost of the appliances used at Kurrachee for lifting and setting 27-ton blocks and the floating shears at Dublin, two things rather dissimilar; but in comparing two systems of construction the total cost of the plant in the one case should be contrasted with that in the other; and he found in the report just referred to that the plant at Kurrachee had cost considerably over £20,000.

Mr. Harrison, President, said there could be no doubt that one of the best tests of an Engineer's ability was the ingenuity with which he could adapt the materials at his command to the particular circumstances of the case; and he did not think that it could be said of any two breakwaters that they were in all respects parallel. He believed the use of concrete was one of those things in which English Engineers were far behind the rest of the world. One reason was that they did not possess so perfect an hydraulic mortar as that which existed in the Mediterranean. He had seen piers constructed with it at Trieste, in a depth of 40 feet of water,

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[1] *Vide* "Kurrachee Harbour." Report, dated 28th February, 1872, by William Parkes, p. 12.

by forming a casing of planks with piles, in the form of the pier, the interior space being filled in with concrete put down through spouts until it was brought up to the surface of the water. The superstructure of masonry was equal to any he had seen in England.

Mr. R. GERVASE ELWES remarked, through the Secretary, that the Engineers, of whom he was one, of the canal now under construction, from the Sutlej River in the Punjâb, early directed their attention to the advisability of employing concrete for the masses of masonry required in the works of art near the head. In addition to a dam 3,700 feet long across the Sutlej River, and the usual locks, regulators, bridges, and escapes, three large 'super-passages,' or over-aqueducts, would convey torrents over the canal, which was 200 feet wide at the bottom, and was intended to discharge 6,000 cubic feet per second. These super-passages varied from 150 feet to 350 feet in width between the head-walls. They would consist of five masonry tunnels side by side, each of 45-feet span, through which the canal water would flow. There was a great dearth of building stone in the district; neither could fuel be obtained in sufficient quantities to burn the immense number of bricks that would be required. On the other hand, shingle and 'kunkur,' or nodular limestone, were abundant. Under these circumstances, Mr. Elwes recommended that the foundations, piers, abutments, and wing-walls of the works of art should be constructed of 'monolithic' concrete *in situ*, and that the arches, at all events of the super-passages, should be built of concrete voussoirs, moulded on the banks, and set in place by a gantry. After some experiments by Mr. Tanner, M. Inst. C.E., which were recorded in the Indian Professional Papers on Civil Engineering,[1] Mr. Elwes, who was then in charge of the construction of a length of 27 miles of the canal, was requested by the Punjâb Government to inspect the Kurrachee Harbour Works, with a view to obtain information regarding the use of concrete in large masses. He accordingly visited the works in the autumn of 1870, and had much pleasure in testifying to the extreme completeness and efficiency of the process there employed, with considerable economy of plant. He was particularly struck with the concrete-mixing apparatus. The revolving boxes had a peculiar angular shape, and their sides were inclined to the axis of rotation. They therefore turned their contents over completely at each revolution, somewhat as mortar was turned over with a shovel, while a cant sideways was at the

[1] *Vide* vol. vii., p. 274.

same moment given to the mass. These combined movements effected a more thorough and rapid mixing, with less expenditure of power, than could be produced by any other form of apparatus he had seen. An ordinary motion of rotation, as, for instance, in a horizontal revolving barrel, tended to separate the heavier particles, while the use of knives or blades, as in a pug-mill, or as in the machine described in the Paper, caused great friction and loss of power, especially where, as at Kurrachee, rubble of considerable size was used as ballast. This inspection of the Kurrachee works confirmed his opinion as to the desirability of using concrete in mass for many of the works on the Sirhind Canal; but no final decision had been arrived at when he left the Punjâb. It might be useful to mention a simple and economical method of mixing concrete, which he had used in large bridges, where mixing machinery was not available. A long, narrow trough, lined with bricks, was provided, the axis pointing towards the spot where the concrete was to be used. At the more distant end there were two tanks for mixing the mortar separately, one being filled and mixed while the other was being emptied. The ballast was stacked close by, and the materials were continually cast into the end of the trough in the proper proportions by measure. As fast as the stuff was thrown in, it was shovelled along, by men stationed at the sides of the trough, to the other end, whence the concrete, thoroughly mixed in its passage, was taken out and carried to its place in the work. The advantages of this method were considerable, as compared with the common mode of throwing the materials in a heap, and turning them over till supposed to be mixed. The labour required was much less, the mixing thorough and equal throughout, the supply continuous, and the concrete consequently fresh. No doubt some reason existed, though not apparent, for the absence of bond in the Kurrachee breakwater. Consisting as it did of nine horizontal prisms, laid in three courses of three prisms each, the prisms themselves made up of blocks set up on end face to face, it seemed to Mr. Elwes, on visiting the breakwater, that a slight alteration in the dimensions of the blocks, to allow them to be laid 'header and stretcher' fashion, breaking joint in the successive courses, would have bonded the prisms together, and have added to the stability of the work, especially in the event of any disturbance in the rubble substructure.

Lieut.-Colonel PLAYFAIR, Consul-General, in a communication to the Board of Trade, dated Algiers, 8th November, 1869, said:—"While I was in the act of penning my annual report, and describing the splendid harbour recently completed at Oran, containing an outer port of 24, and an inner basin of 4 hectares, 740 metres of breakwater, and 300 metres of quay, I received a despatch from the Vice-Consul there, containing the particulars of a frightful storm which burst over that neighbourhood on the 1st instant, and utterly destroyed all the great works which had been accomplished. On the 30th and 31st ultimo a strong northerly wind and heavy sea set in, but no serious damage was done till Monday the 1st instant. At 11 o'clock on that day the wind increased in violence, the sea, dashing in white foam over the breakwater, entered even the inner basin, and speedily scattered the immense blocks of concrete of which the jetty was composed, leaving not one standing on the other. Not only does the Port of Oran now offer no shelter for shipping, but the débris of the breakwater constitutes a source of actual danger, which vessels will do well to avoid."

February 17, 1874.

THOMAS E. HARRISON, President,

in the Chair.

The discussion upon the Paper, No. 1,376, "On the Construction of Harbour and Marine Works with Artificial Blocks of Large Size," by Mr. B. B. Stoney, was continued throughout the evening.