Mr. PARKES said there could be no doubt that the application of cement concrete to marine works was one of the great features of the engineering of the present day. The methods described in the Papers appeared to have been both well devised and carried out in a practical way. He offered no opinion as to whether the plans adopted by Mr. Cay for Aberdeen were suitable to the place. The point to be considered was the limit within which such plans were applicable at other places. With regard to the concrete in bags, if the object was to make a very solid foundation, he thought it was fully attained, but at a rather heavy cost; and in cases that might appear somewhat similar to that of Aberdeen, he should not take it for granted that the system there pursued was necessarily the best. The liquid concrete deposited in bags cost about 25*s.* per cubic yard; that which was deposited above low-water level in frames cost 16*s.*; so that the sum of 9*s.* per cubic yard was due to the extra expense of the former. There was an item for excavating the foundations of the breakwater—£3,835—which, with the 9*s.* per yard for 3,202 cubic yards, or £1,441, gave a total of £5,276 for 45,000 superficial feet, or about 2*s.* 4*d.* per superficial foot. Nor was that all the cost. It appeared that the only real use of the staging was for depositing the concrete in bags. No doubt it was afterwards employed for setting blocks, and putting in concrete in the upper works; but it was by no means necessary for either the one or the other. The money spent upon the setting machines would have provided a Titan to set the blocks off the end of the work as easily, or more easily, than they were arranged from the staging; but it would have been impossible to put in the concrete bags from a Titan. The cost of the staging, therefore, must be added, because it would not have been necessary but for the particular method adopted for the foundation. That cost was upwards of £10,000, so that the total cost of the foundations exceeded £15,000, or 7*s.* per superficial foot. Mr. Parkes knew from experience that where rubble stone could be put in for a foundation, the cost of preparing it to receive the superstructure did not exceed about 1*s.* 6*d.* per superficial foot, so that 5*s.* 6*d.* might be regarded as the extra expense of the concrete foundation, and it was a question whether the additional solidity gained was an equivalent for that amount. It might be so at Aberdeen and other places, but it ought not to be taken for granted that it was so in every case. He wished to bear testimony to the ingenious way in which the work had been devised, especially the plan of putting the bag into a hopper. The bag was somewhat larger than the box, so that, on being discharged, it spread out and

accommodated itself to the bottom. With regard to the concrete blocks of from 10 to 20 tons, he agreed in the opinion that the plan was not altogether faultless. He objected, however, more to the variety in the size than to the size itself. The same apparatus was required for setting blocks either of 20 tons or 10 tons, and the cost was as much for the latter as for the former, though only half the quantity of work was done. The answer to that probably would be, that to bond the work there must be blocks of different sizes. He thought, however, that bonded work was a mistake; the blocks should be of uniform size, resting upon one another, and in no case should one block rest upon two. It was admitted that a block might bridge over a settlement, so as not to rest upon the one below, in which case the latter might be drawn out by the sea, and a hole be made in the work. That could not happen if the blocks were placed one above another in a columnar form. He entirely approved of the capping of concrete *in sitû*, and particularly of its not being continuous longitudinally. He did not think it was right to attempt anything longitudinally rigid for sea work. No additional stability was gained by an increase of length in the parts. The superstructure, he believed, would be just as stable in a series of vertical slabs extending the whole width of the breakwater as in a continuous length of concrete. The Author had arrived at the conclusion, from practical considerations, that about 16 feet was the right length for the slabs; but he thought that 8 feet would be quite as good. It was of great importance that the several sections of the superstructure should be detached from one another, and allowed to have some movement, however slight, between themselves, so as to follow any settlement in the works below. It had been stated that the blocks below low water, and up to a little above low water, should be from 100 to 200 tons in weight. That, he thought, depended upon the facility with which they could be placed. If the blocks were large, there was great expense in placing them, otherwise the larger the block the better. He should be glad if some reasons were given for the particular dimensions adopted for the breakwater, namely, 35 feet in width and 11 feet above high water. The breakwater at Kustendjie was only 12 feet wide at the top. He congratulated Mr. Cay on the success of this work, and hoped that the extension of the North Pier would be equally successful.

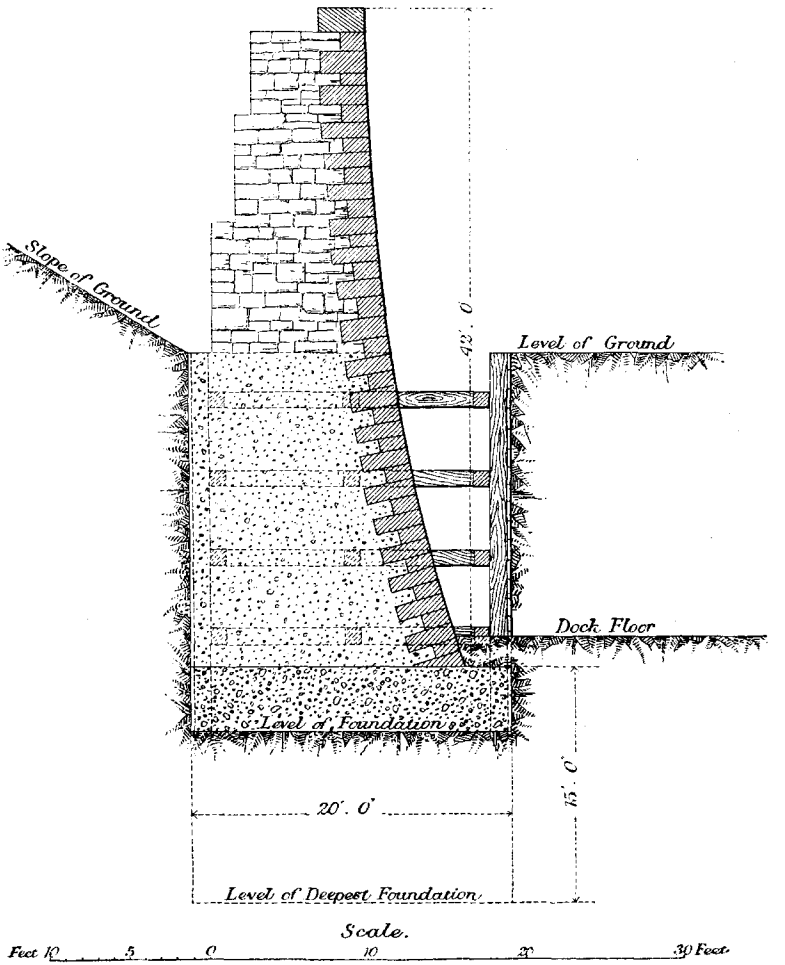
With regard to the jetty at Kustendjie, one feature of the work was the contracted space in which it had to be carried on, so that only twelve blocks could be in hand at one time. That appeared to have necessitated the adoption of the system of putting the

blocks into the work in a fresh state, when not more than twelve or fifteen days old. He had himself striven to reduce the time during which concrete blocks were allowed to set. There was a feeling among engineers, and still more among foremen, that they ought to be allowed a long time to harden. He was not of that opinion. In one case, a block of 27 tons was taken up and put in place ten days after construction, and nothing went wrong. That fact gave to the persons connected with the works some confidence, and after that they were used when a month old. If twelve or fifteen days were sufficient at Kustendjie, there was no reason why blocks should be kept occupying space even for a month. The work at Kustendjie reflected great credit on the designer, Mr. Liddell, as well as on the Author of the Paper.

Mr. BRUNLEES said, about six years ago he had used concrete blocks for the foundations of a dock at King's Lynn, and also concrete for pitching the slopes of the dock. Those slopes had been exposed for six years to the weather and to the bumping action of vessels, and he was glad to say they were as sound as when put down. The Papers did not deal with any great extent of work, but they were valuable in pointing out the way in which similar works might be conducted. The breakwater at Aberdeen had been, no doubt, conducted very successfully. His attention had, however, been drawn to one item, namely, that £46,000 worth of work had been done at an expense of £30,000 for plant, preparatory works, and buildings, which seemed an enormous proportion. He was at present using cement concrete for the dock at the mouth of the Avon, near Bristol. The walls (Fig. 1) were built in a trench, piles being driven on each side. Stretchers were then introduced as the excavated material was taken away. The foundations were of blue lias concrete generally to a depth of 6 feet below the level of the dock floor, but at other points, where the ground was weak, to a depth of 17 feet below the same level. On the blue lias concrete, and from 2 feet below to 18 feet above the dock floor, the wall was built of cement concrete faced with Pennant stone. The concrete was tipped into the excavation from the surface out of barrows, and at the back it was rammed against the piles and poling boards. The front of the wall was carried up in rubble at the same rate at which the cement concrete was put in. The upper part of the wall was of coursed rubble of the ordinary description. It was found that in twenty-four hours the concrete was well set. For a work of that kind, where the ground was weak and slippery, the method pursued was very appropriate, as it tended rapidly to consolidate the cement concrete, and he had every reason to be satisfied with

the results. The lias concrete cost 9*s*., and the cement concrete 14*s*. per cubic yard. To cheapen the cost of the latter he had tried mixing it with blue lias, but had not obtained the object hoped for.

FIG. 1.



BRISTOL PORT AND CHANNEL DOCK.—SECTION OF EAST WALL.

Mr. GRANT agreed with the Author, that it would have been better if the work below low-water level had been executed with liquid concrete in bags, instead of with blocks, as now proposed for

the extension of the North Pier. That mode would have saved a great deal of the cost of the heavy staging and plant, amounting to £23,217, or 30 per cent. of the whole cost, and also of the extra expense of making and setting the blocks. He believed, when the new work came to be carried out, that the foundation would be actually more solid than the work already done with blocks. He thought the work would have been sounder if, instead of being in sections averaging about 20 feet in length, and executed from 1 foot above low water to a height of 18 feet at one operation, it had been carried out by steps. In the Thames Embankments, from 8,000 feet to 9,000 feet in length, the mode adopted was to lay the concrete in such a way that for every foot in height there was an advance of at least 3 feet forward. By that method more perfect homogeneity of construction was secured, and the chance of vertical fractures avoided. The plan had also the advantage of graduating the work, so that no excessive weight was suddenly brought upon any part, and there was no unequal settlement. This was of great importance, not only in a constructive point of view, but in point of economy. To protect the surface from the wash of the returning tide it might be coated with Roman cement-grout or other quick-setting cement. He was of opinion that when the further works at Aberdeen were carried out, this plan would prove advantageous. The cost of the staging and plant, in proportion to the outlay, certainly seemed excessive. He had calculated the prices as follows:—Concrete deposited liquid in bags, 25*s.* 3*d.* a yard; concrete used in the apron, 44*s.* 6*d.*; concrete blocks and block-making, 13*s.*; concrete deposited liquid in frames above low-water level, 16*s.* 2*d.*; average 15*s.* 9*d.*, to which 10*s.* had to be added for plant and sea staging. The prices paid in the Thames Embankment recently finished at Chelsea were, including setting, 10*s.* 6*d.* for liquid concrete, where the proportions were 8 of gravel to 1 of cement; 12*s.* for liquid concrete, where the proportions were 6 to 1; and 16*s.* for blocks, the proportions being 6 to 1. Of course, there might be good reasons for different prices in different places; and, generally, the cost of blocks must be several shillings a yard more than the cost of liquid concrete. Every movement of heavy materials added to their cost; and in the case of cement blocks, there was not only the cost of making them, but also of moving and setting them. With regard to the cement used in the work, the specification was that the trial brick should bear a tension of 600 lbs. on an area of $2\frac{1}{4}$ inches, which was equivalent to 260 lbs. per square inch. The standard, adopted for several years by the Metropolitan Board of

Works, was 350 lbs. per square inch, or 787 lbs. on $2\frac{1}{4}$ inches. He should be glad to know the cost of rubble at Aberdeen, for the purposes of comparison. Upwards of five hundred experiments had been made for Mr. Brunlees, which justified the course taken by him for the dock near Bristol, in keeping the lime and cement concrete for different parts quite distinct. No advantage would have been gained by using a mixture of lime and cement.

Mr. G. R. STEPHENSON, Vice-President, thought the Paper should have contained some account of the effect of the sea upon the walls at Aberdeen. The manner in which piers were now made was very different from that formerly adopted. Many harbours were being treated simply as ditches leading from the land into the sea, and he was satisfied that was wrong. He should like to know how the work in question affected the entrance to the harbour in regard to ships going in. In these days, little or no attention was paid to the position of the piers, which ought to be such as to admit of vessels running safely in, seeing that steam-tugs were always available to tow vessels out. His impression was that the south pier was not in the best position. With an easterly or a south-easterly gale, it would be difficult for a vessel to go round the pier and get into the harbour; and when the North Pier was carried out, he thought the difficulty would be still greater, inasmuch as, he believed, the range into the harbour would be increased.

Sir JOHN HAWKSHAW, Past-President, remarked that he could not concur in the opinion that those who had to construct harbours neglected to consider the way in which vessels should get in or out. It would be a great slur upon them if they did so. He thought great credit was due to Mr. Cay for the manner in which the work at Aberdeen had been carried out, and particularly for the mode in which a portion had been constructed of concrete deposited liquid. It had apparently been forgotten that the Aberdeen breakwater was built in the sea, and not with coffer-dams in the Thames. He believed it would have been quite impossible to build the pier in the way suggested by Mr. Grant. He knew of no kind of staging by means of which the work could have been so constructed. Then with regard to the cost of concrete in the Thames and at Aberdeen, the sea was subject to storms, which stopped the work, and often prevented the men from doing more than a third of a day's work in a day, and this alone would account for the difference. Supposing the staging and plant, instead of being retained for further use, had been sold for one-fourth of the original cost, which was not putting it at too high a price, the work all round would have cost about 28*s*. per cubic yard, which

certainly was not a high figure for work of that description. It was said that all blocks below low water should be from 100 tons to 200 tons in weight. The size of the blocks, however, should have relation, not only to the sea, the particular locality, and the cost, but also to the depth at which they were placed. At Holyhead, where the water was 70 feet or 80 feet deep at the end of the breakwater, it would not be of the slightest use to employ a block of 200 tons weight, while the operation itself would be very difficult. At great depths the size of the blocks was not of much consequence. The bottom of the ocean might be composed of mud, sand, and very small gravel. If the method referred to by Mr. Grant had been adopted, in the event of a ship coming close to the side of the breakwater, the bilge would strike against the projecting concrete, and the ship might be destroyed. No general rule could be laid down; but the work must be adjusted according to the circumstances of the case, and often according to the money to be expended. He was surprised to hear an observation with regard to the difference in the width of the two breakwaters under discussion. In many seas, a breakwater 12 feet wide would be of no more use than a sheet of paper; the sea would pass through it as soon as it was built, if it were built at all. The thickness must depend upon the impact of the sea. In some cases the thickness of the breakwater at Aberdeen would be insufficient. At Wick, a block 45 feet wide, and weighing 1,400 tons, had been moved by the sea bodily and horizontally, and shifted landwards. It was, therefore, no matter of surprise that some piers had to be made broader than others.

Mr. ALFRED GILES thought it was unfair to argue that the cost of the plant was 30 per cent. of the cost of the breakwater. The southern breakwater was 1,050 feet in length, and the projected North Pier was of about equal length; the same plant would be available for both, so that the cost would only be 15 per cent. on the whole work. If a Titan were used, the foundation of the breakwater must first be made, and that would take much longer than would be required for the staging. It was thirty years since he used concrete deposited liquid *in situ*. He did not employ bags, but discharged the concrete across a lock entrance by means of a shoot. If the 100-ton bags used at Aberdeen burst when they got to the bottom, he thought a shoot would be quite as efficacious, and much more economical, and would probably answer in the construction of the North Pier. He should be glad to know whether any advantage had been found to result from the use of fresh water instead of salt water for the concrete. As the

breakwater, including a great part of the staging, was executed at a cost of £65 per lineal foot, there was not much to complain of in respect to the general expense. He thought there was not the slightest analogy between the cost of work on the river walls of the Thames and that at an exposed place like Aberdeen.

Mr. ABERNETHY remarked that the old breakwater was originally constructed in 1812 by Mr. Gibb, the then resident Engineer, who consulted Mr. Telford on the subject. The object was not to protect the entrance of the harbour, but the piers then in progress. Mr. Telford pointed out that if the old south pier was not extended parallel with the north pier to the full length, the effect would be a contraction of the harbour entrance and the formation of a shoal within the north pier-head. That result followed, and the state of the harbour entrance from 1812 until the end of last year was just as had been anticipated. It was obvious that as the end of the breakwater was immediately opposite the termination of the north pier, it could afford no protection from south-easterly seas, and that the danger to vessels entering during those gales would be increased. Therefore, as far back as 1846, the subject of moving the breakwater farther seaward was brought before the Harbour of Refuge Commission, and again in 1850 before the Harbour Commissioners of Aberdeen, also in 1860 and 1862. In 1867, Mr. Cay, adopting suggestions that had been thrown out for many years, brought forward a plan for the removal of the breakwater seaward and the extension of the North Pier. With certain modifications in the direction of the breakwater, and also in the details of the North Pier, made by Sir John Hawkshaw and himself, the plan was being carried out. Mr. Cay deserved great credit for the way in which he had completed the work, and for the substitution of concrete deposited in a liquid condition for blocks above low water. With regard to the section of the North Pier to which reference had been made, no doubt the bags would form an excellent foundation, but they should not be carried up to the level indicated, because there would be an open joint along the whole face between the mass of solid concrete and the bags so deposited. He was of opinion that blocks of concrete, or concrete *en masse*, should be carried considerably below the level of low-water.

Mr. CAY, in reply upon the discussion, said the staging was determined on before the bags were thought of, and was meant to serve for building the blocks. The staging was preferred to a Titan crane, as, to make rapid progress, the latter would have required an almost impracticable extent of overhang, owing to the

arrangement of the bond of the blocks, the height of the work, and the foundations, the excavations for which had to be prepared in advance of the building. Under these circumstances it was unreasonable to charge the expense of the staging exclusively against the bag-work in the foundations. The cost should be charged to the concrete blocks and to the apron. In reference to the relative expenditure, the plant and buildings were intended to be used for another similar work at Aberdeen. That under discussion was shorter than had been originally intended, so that the cost of the plant should be distributed over a larger amount of work than had been described in the Paper. As the working season in each year was short, the exposure great, and the total expense and risk depended very much on the number of years occupied, the use of a powerful plant was advisable and economical. In any case the relative cost of the plant for sea-works should not be compared with that for structures on shore, or in the interior of harbours.

Making allowance for part of the cost of the plant, buildings, &c., being charged against the northern extension, or for their being sold, and adding for some expenditure incurred since the 30th of September, 1873, the following was the revised statement of the work and expenditure :—

	Cubic yards.	£.	s.	d.	£.	s.	d.
Excavating for the foundations of break-water	..	3,869	14	7			
Concrete deposited liquid in bags in the foundations	3,202	4,045	5	2			
Ditto ditto in apron, including part of the cost of the plant	1,336	2,052	1	9			
Concrete blocks and block-making	22,851	14,839	6	7			
Block-setting	ditto	3,350	18	10			
Concrete deposited liquid in frames above low-water level	23,972	19,741	13	8			
Lighthouse	..	353	9	8			
					48,252	10	3
Preparatory works					2,796	14	9
Buildings					1,107	12	11
Plant					6,319	8	5
Sea staging					8,311	18	8
Sundries					1,309	5	6
		Total			£68,097	10	6

That sum deducted from the total expenditure left £9,878 2*s.* 4*d.* as the value of plant, buildings, rails, masts, and materials in hand to be charged to other works, or to be sold. Dividing the expense of plant, buildings, staging, &c., in due proportions over the dif-

ferent parts of the work, their relative cost was approximately as follows :—

Description of Work.	Cubic yards.	Approximate price. £. s. d.	£. s. d.
Excavating for the foundations of the breakwater	..	..	4,904 14 7
Concrete deposited liquid in bags in the foundations	3,202	1 15 5	5,712 16 5
Ditto ditto in apron	1,336	1 17 0	2,473 15 2
Concrete blocks and block-making	22,851	0 16 1	19,259 3 3
Block-setting	ditto	0 11 5	13,079 17 8
Concrete deposited liquid in frames above low-water level	23,972	0 18 7	22,283 13 9
Lighthouse	..	..	383 9 8
Total as above			£68,097 10 6

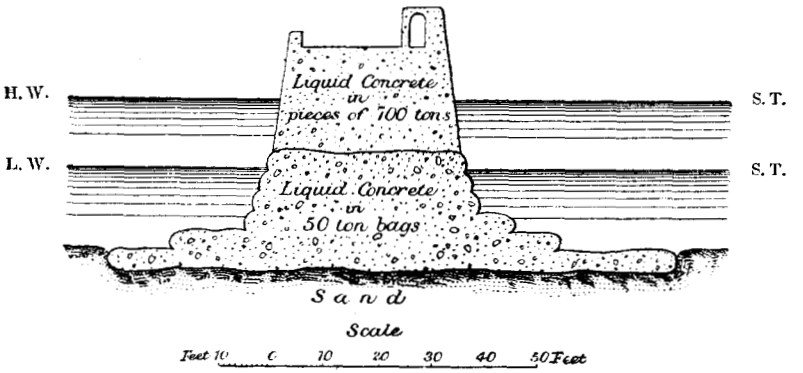
Had the breakwater been carried out to the length originally intended, it would have cost about £10,850 additional, making a total of £78,947 10*s.* 6*d.*, which agreed closely with the preliminary estimate.

The item for excavation for the foundations referred to the removal of loose stones, gravel, and sand, which would be requisite under any system of procedure, so that its cost should not properly be taken into account in the comparison; the expense of this preliminary work, however, for that part of the breakwater founded on bags was about 2*s.* 4*d.* per superficial foot. As the cost of the bag-work per cubic yard was £1 15*s.* 5*d.*, and that of a corresponding bulk of concrete block, for which it was substituted, was £1 7*s.* 6*d.*, the sum to be charged to the expense of preparing foundations by this system was 7*s.* 11*d.* Each square yard required on an average $\frac{4}{5}$ cubic yard of concrete in bags; thus the cost per square yard was 6*s.* 4*d.*, or per square foot about $8\frac{1}{2}$*d.*

In the extension of the North Pier, about to be carried out, a section of which was shown in Fig. 2, and of which a model was exhibited, the foundation was sand, with solid ground at a depth of 7 feet below the surface. The whole of the submarine part, from the foundations to about 3 feet above L. W. O. S. T., a height of 22 feet, was to be formed of bags, each containing 50 tons of liquid concrete. A wide platform of these bags would be first laid as a foundation, and would be left to settle into the sand. When consolidated by the action of the waves, bags of concrete would be deposited on it, so as to bring the surface above low water, above which the work would be entirely of concrete deposited liquid in frames, in pieces of about 700 tons each. The 50-ton bags would

be deposited by a hopper barge, similar to that used for depositing dredgings, except that the slope of the well in the middle of the vessel would be modified. The precise spot for the bags would be fixed by lines ranged at right angles to one another by marks

FIG. 2.



ABERDEEN HARBOUR.—PROPOSED EXTENSION OF NORTH PIER.

on the shore and the pier, and the barge would be securely moored during the operation by six chains and rope warps, with six winches on deck for heaving on them and bringing the barge to its proper position. The contract price for such a barge delivered at Aberdeen was £2,302; that of a barge to deposit 100-ton bags of concrete was only £3,300; and though its first cost was £1,000 more than the vessel for depositing 50-ton bags, owing to fewer workmen and less time being required to deposit a given quantity of concrete, the larger vessel would be the cheaper of the two to employ in a work of great size.

The New South Breakwater had answered the purpose intended, and vessels could now enter the harbour during southerly or south-easterly gales. The only danger at present to be apprehended during storms was from the breaking seas caused by the shallow water on the bar; this danger it was expected that the extension of the North Pier would obviate, as thereby a greater depth of water at the entrance would be secured and the bar be removed. An increase of depth of 10 feet was expected to be obtained at the entrance by the combined effects of dredging and the extension of the North Pier by 1,000 feet.

Sir JOHN COODE, through the Secretary, remarked that he had

been the first to employ Portland-cement concrete for the external work of sea piers, having so used it about ten years since, not only for the facing of the main walls, as well as for the backing, but also in parapets, copings, and paving blocks in a pier exposed to the North Sea. He had also largely and continuously adopted it since that time in other sea works. He was glad, therefore, to find that the use of concrete for building breakwaters was rapidly extending, for his confidence in this material increased as time progressed. It would have been an advantage if more definite information had been furnished as to the extent to which the concrete in the 100-ton bags had suffered by the fall, when dropped from the box supported on brackets, as described in the Paper on the Aberdeen breakwater. The system of forming concrete foundations by bags deposited from iron skips had been successfully employed, and it was believed for the first time in the United Kingdom, in some sea walls constructed under Mr. James Barton, M. Inst. C.E., at the New Harbour at Greenore, in Carlingford Lough; and the deposition of liquid concrete *in sitû* within three-sided frames lined with bagging had also been effected in a steam-packet pier at Douglas, in the Isle of Man, prior to its employment at Aberdeen. From the experience gained at Douglas, Sir John Coode could recommend the practice for moderate depths of water, especially where the bottom on which it was required to found the work was rocky and uneven; but this, like every other system, had its drawbacks, and was not suitable for all cases.

Mr. STONEY observed, through the Secretary, that the deposition of 100-ton masses of concrete in bags was an ingenious and valuable addition for protecting the toes of breakwaters in comparatively shallow water, where the depth was not sufficiently great to prevent the waves moving an ordinary rubble foreshore, composed of stones of from 3 tons to 4 tons in weight. This would in most localities vary from 9 feet to 12 feet below low water; at greater depths, stone would be much cheaper than, and equally efficacious as, large bags of concrete, which in the Aberdeen breakwater apparently cost £2 4*s*. 6*d*. per cubic yard. For the extension of the North Pier it was proposed to use large blocks of concrete of from 100 tons to 200 tons deposited liquid in bags, to form that portion which was below low-water level. Mr. Stoney thought there would be some difficulty in this, in consequence of the tendency of such large soft masses to spread and burst the bags, unless deposited within frames. However, the Author's experience might have suggested means of overcoming this difficulty. Mr. Stoney had, about six years since, successfully deposited a

large quantity of concrete under water in ordinary sacks, such as those used for holding corn. Each sack contained 6 cubic feet of concrete, which weighed a little more than 8 cwt. The cost of the sacks was at the rate of 3*s.* 2*d.* per cubic yard of concrete, but this item might probably be reduced if a large quantity of sacks were bought by contract. When laid in tiers over each other, an upper tier fitted into the inequalities of the one below, and though the cohesion of sack to sack was not equal to that of concrete to itself without the interposition of sacking, yet they dovetailed into each other and formed a capital wall so long as the foundations were unyielding. In this respect he fully agreed in the remark, that blocks of 10 to 20 tons in the lower part of vertical breakwaters, similar to that at Aberdeen, appeared to be their weak part, for, if the foundations turned out to be soft material, a slight yielding would allow the blocks to be loosened and broken up by heavy seas. Moreover, it must always be difficult, if not impossible, to thoroughly bed these blocks when under water, for mortar could not be laid between them, and, consequently, the majority of such blocks must be supported at their ends only, or unequally. For this as well as other reasons, large blocks of from 300 to 500 tons each would form the best substratum of a vertical wall. Mr. Stoney believed the only feasible method yet proposed for the purpose was that he had already described[1] for building large blocks on *terra firma*, and then conveying them afloat to their destination in fine weather. He might add that the blocks now being employed at Dublin Harbour were 29 feet in height, or 2 feet higher than those described in the Paper. The loss of iron tie-rods in masses of concrete built within frames might be obviated by placing two narrow boards, nailed together in the form of an inverted **V**, over the tie-rod before throwing the concrete around it. This would form a small tube in the mass, and permit the withdrawal of the tie-rod when the concrete was hard.

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