Discussion.

The President. The PRESIDENT, in moving the vote of thanks, asked how far below the surface any action of the sea was felt. Probably the Authors had obtained some valuable data in the course of building the high bank. The limit of such action was generally taken as about 12 metres (40 feet), but it would be interesting to know whether observations made by the Authors tended to confirm or alter that view.

Mr. Wilson. Mr. MAURICE F.-G. WILSON remarked that the Paper raised several interesting questions, in particular the question of the depth below the surface to which the effect of wave-motion was felt. There were several unusual points in connection with the construction of the breakwater at Valparaiso. It would appear that the depth of water in which it was built was as great as 150 to 200 feet. To overcome that the engineers had dumped sand so as to form a submerged bank, on top of which they had deposited rubble in the ordinary way, whilst on the top of the rubble the solid breakwater had been built. The usual experience was, where a solid breakwater was placed on top of a rubble mound, or otherwise founded, that the waves struck downwards when they encountered the breakwater, and disturbed the mound, or the underlying material forming the foundations, to a considerable depth. It would be very interesting to know whether the sand forming the sea bed had been disturbed in the course of years. The breakwater at Peterhead, for which his firm were the engineers, was less exposed than that at Valparaiso, which was exposed to the full Pacific Ocean. At Valparaiso the foundations were placed at 39 feet below low-water level, with a comparatively small protecting apron on the seaward side about 25 feet wide and about 3 feet thick, whilst immediately outside the apron there was rubble sloping away at about 1½ to 1, and apparently nothing had been disturbed—at least there was no reference in the Paper to any disturbance of that part of the work. The work at Peterhead was exposed to the North Sea; the fetch was not nearly so great as at Valparaiso, though undoubtedly the seas were very heavy. The foundations of the solid work were placed at a depth of 43 feet below sea-level. The rubble mound was protected by an apron 51 feet wide, formed of concrete blocks weighing 50 tons each. Outside the apron, for a width of 25 feet, there were placed very large rubble stones up to 10 tons in weight, and outside that again there was the rubble standing at the natural slope of about 3½ to 1. That was very ample protection compared with what was given at Valparaiso.

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There had been great trouble all through the construction of the work at Peterhead, and during winter gales the rubble mound and the concrete apron were constantly disturbed; in fact during one gale a 50-ton apron block had been lifted out of place and turned on its back. The surface of this block was more than 40 feet below sea-level. Since the work was completed there had not been much trouble, but even now displacement of rubble occasionally occurred and had to be made good. Therefore it astonished him to find that at Valparaiso, with apparently much greater exposure and comparatively little protection to the rubble mound, no damage had been done. It seemed to him that there might be two explanations of that. First, that the breakwater ran at a very oblique angle to the direction of the heavier waves, and secondly, that the seas were not really so heavy as the exposure might lead one to expect; otherwise he was sure there would have been some disturbance of the work. The foundations of the Antofagasta breakwater were placed even higher than at Valparaiso; it had also a narrower apron and, generally, was less protected. Further, the breakwater ran at right angles to the direction of the heavy seas, and therefore it might be expected that the wave-stroke there would be very heavy. Yet the Authors stated that there had been no disturbance whatever of the rubble, and from that fact they deduced that there was very little horizontal movement of the water. That might be so; but it would be interesting to have further particulars as to the direction and weight of the seas. Another curious thing about the Antofagasta breakwater was that the engineers had apparently calculated the thickness of the breakwater from the static head. He did not understand how a breakwater could be calculated in that way. He doubted even if the dimensions of a breakwater were susceptible of mathematical calculation. The hydrostatic head of any wave was a comparatively small matter; the danger to a breakwater came from the wave stroke and the resulting hammering of the breakwater; and that was very difficult to measure. At Peterhead there was a mass of concrete extending from the breakwater surface down to about 30 feet below low water, and weighing about 32,000 tons; yet that had been moved bodily about 6 inches, due to wave-stroke. Calculations based on some experiments which had been carried out there tended to show that a pressure of about 2 tons per square foot must have been exerted over the whole exposed surface, which would be very heavy. He would like to know more about the wave-stroke at Valparaiso, and why it had been assumed that it was quite sufficient to take the hydrostatic head in calculating the dimensions of the breakwater. With regard to the work itself, the bonding of the blocks seemed to be very effective, each slice being bonded transversely into the adjacent Mr. Wilson.

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Mr. Wilson. slices by means of large joggles moulded in the blocks. An effective bond was absolutely necessary in such work. He could instance two breakwaters with heavy sloping bond blocks in which there was no such bonding; and the result had been that the sea undermined the foundation outside the breakwater—the rubble or sand, as the case might be—and the outer row of blocks fell seaward, simply because they were not properly bonded. The opening of the lower joints as referred to in the Paper was apt to occur in all slice-work when set over end. At Colombo breakwater tapered blocks had had to be made, to be put wherever it was found that the lower joints were opening so much that the blocks were getting out of proper inclination. In this connection he might mention that in a quay-wall he had built, formed of sloping bonded blocks set from staging, no creep at all had occurred. When sloping blocks were set by sliding them down over the end of the work, they were apt to slide forward on striking the bed, thus slightly opening the lower joints and reducing the angle of slope so as to necessitate adjustment as stated in the Paper. When blocks were set from a staging that tendency of the bottom blocks to slide forward did not occur. The Paper was exceedingly interesting, and he hoped the Authors would be able to tell the members more about the sand bottom in a few years' time. He could not help feeling that there was some risk of its being disturbed.

Sir Ernest Moir. Sir Ernest Moir observed that the points raised by Mr. Wilson had, of course, obsessed from the first those responsible for building the structure. Originally the mound was to have been composed largely of rubble and sand, but it would have been so expensive and would have taken so long to construct by that method that the contractors had been bold enough, in a lump-sum contract, to undertake the whole thing in sand, and the engineers had been bold enough to accept that scheme. He thought, therefore, that congratulations should be shared both by Messrs. Davila and Lira and by Messrs. S. Pearson & Son for their pluck. The work could not possibly have been carried out, and, he submitted, British contractors would not have secured the contract, but for the fact that savings were made by that means. As to the stroke of the seas, there was no historical evidence of any material disturbance by wave-action down below. The only case of disturbance by wave-action had occurred at the top, due to leaving a channel for constructional purposes along the breakwater section shown in the Paper. That channel had provided an excellent key for binding the whole breakwater together as finished; but in a heavy storm it had filled with water, and the heavy seas falling on it had acted like a hydraulic ram and forced some of the blocks on the lee side away from their original positions. As Mr. Wilson had pointed out, the cross bond on that wall was extra-

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ordinarily well designed, and had it not been of such a character as the Paper showed, the inside of the breakwater would probably have been carried away. Some of the joints had opened approximately 3 inches, or had gone as far as they could before the bonded blocks prevented them from going farther. Of course, no one would advocate the use of sand as a foundation under different conditions from what were found at Valparaiso. It was a very important point that at Valparaiso there was no longitudinal current. If there had been a current of, say, 3 feet per second, or something like that, running along the wall, or if the Humboldt current had not favoured them by being some miles out at sea, the method of founding the breakwater would probably have been rather a precarious one. On the other hand, there it remained and there he thought it would remain for an indefinite period, because apparently, whatever cause might have brought about the destruction or partial destruction at Peterhead, clearly those forces did not operate at Valparaiso. The sea did not strike down 114 feet—it would be noticed that there was no sand nearer than 114 feet from the surface. At Dover harbour he had noticed that even small stones had not been moved at 42 feet. He thought Mr. Wilson would remember that. He referred to stones lying on the aprons. [Mr. WILSON said they were on the rock.] Even on the apron blocks they had not moved, and therefore it seemed inconceivable that any sea anywhere should strike down as deep as 114 feet. He himself would not have advocated anything nearer the low-water mark than 45 feet, but the evidence at Valparaiso did not point to that being a limit, and therefore there was nothing to guide other members or himself in the future. He would, however, strongly advise that sand should not be put anywhere where a longitudinal current was likely to exist. The work itself had been carried out under the Authors' direct supervision. His own visits, of course, had been infrequent, and in regard to details of what the sea did or did not do he could only point to the results observable to-day. So far as he knew, no observations of pressure or anything of that character had been made; and he did not know that the engineers (who were the same as those for the Antofagasta breakwater), had taken the hydraulic head. The wave which they had originally fixed and specified (fortunately for the contractor—he could say that advisedly) was 6 metres. It had been proved that the height of the wave which destroyed the Antofagasta breakwater was 9 metres. That had got the persons concerned out of a difficulty which would otherwise have been troublesome. There had happened to be one of the Pacific Steam Navigation Company's vessels in the port at the time, and observations were taken. The Antofagasta breakwater, he thought, had been carried away because the material

Sir Ernest Moir.

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Sir Ernest Moir.

forming the foundation was too light and too near low water; and it was rather remarkable that the smaller the breakwater and the nearer the movement of the sea was to the horizontal, the greater ought the weight of the bottom masses to be. It might be argued, "This is a small breakwater, therefore put in small blocks"; but if there were very heavy seas it was necessary to employ large blocks, the point of greatest danger being near the shallow water. At Valparaiso many random rubble blocks had been put on the original piece of breakwater, from which the work described in the Paper had started, in order to break up the seas. As to what had happened at Peterhead, he personally felt that engineers had not investigated sufficiently the air-pressures that arose through breaking seas, and the effect which they had on breaking waters. One thing that had helped at Valparaiso in connection with the sand foundation was the fact that when sand was dropped through such a depth of water everything of a light character—shells, mud, and things of that sort—was washed out of it, and the sand that reached the bottom formed a material so hard that an anchor-fluke would not enter it. There were mysteries about everything in engineering. Engineers would never advance unless somebody had the courage to do new things and adopt new ideas; and a great deal of courage had been displayed in the work described in the Paper. He regretted that it was the last work that Messrs. Pearson would do of that character, and in view of the great things the firm had done in the past he regarded that fact as a calamity. He could not help singing that "swan song" at a time which to him, who had been associated with the firm for 42 years, was one of the saddest periods of his life.

Mr. Thomson.

Mr. Thomas Thomson thought that one of the most striking things about the work was its very high cost in comparison with the very small area of sheltered water which it afforded. The two breakwaters—the short breakwater at the end and the 700-metre extension—had cost £1,908,000. It was rather difficult to say what water was sheltered. On a narrow estimate it might be said that only the water from the end of the breakwater to the end of what was marked as the Fiscal Quay was sheltered, and that was only 70 acres in extent. As a matter of fact, for most seas at Valparaiso the breakwater sheltered right down to the other side of the mooring-jetty, which was a much larger area; but, even so, the cost was exceptionally high for the area protected. Of course, Valparaiso was a very exposed port. Originally vessels had moored out in the bay, at strong permanent moorings, cargo being taken in from, or discharged to, barges, which unloaded at small quays. That had sufficed for perhaps 330 days of the year, but during the 20 or 30 days when violent storms occurred—"northers" as they were called in those

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parts—often either the attachments of the vessels to the moorings, or the moorings themselves, had given way, and vessels had been wrecked on the beach; so that even a small amount of shelter for vessels during storms of that description was very valuable. In considering this plucky job, as Sir Ernest Moir had characterized it, at the beginning one disturbing fact had been that when stone or sand was dropped through 200 feet of water, quite a large quantity did not drop vertically, but wandered aside. Anyone who from the deck of a steamer in the tropics had watched natives diving for coins must have been astonished at the way the coins wandered about in the water. In the same way particles of sand or pieces of rubble of a disk shape were liable to wander quite a long way. In order to see if anything could be done to prevent that, some model experiments have been made by dropping sand and gravel through a tube. It was found that if the tube was small and the bulk of its area was occupied by the material, the water was carried down with the sand or stone and when the material reached the bottom it spread out. So that was not a cure. If the cross-sectional area of the tube was enlarged sufficiently to stop that action, the tube became too large. A tube of a size to suit the door of a hopper, or anything of that sort, was a most unwieldy thing, and the problem of handling it in a seaway in 200 or 150 feet of water, was too much to contemplate. Another method which might have been used to get over the difficulty was to lower the material in large boxes. That would have been quite satisfactory but very costly. The experience of a month or two had shown that although there was a loss, it was not so serious as to warrant going to any great expense to avoid it. The Authors expressed preference for a sand-pump dredger with a central well. In many ways a central well was better than a side pipe, but it had one great drawback. It was impossible to build a vessel with a central well of such a good shape for getting through the water, and therefore a dredger with a well was always slower than one without a well. When there was a run of 15 or 20 miles that made quite a big difference. The old dredger, the "Mexico," had a feature which was not common in sand-pump dredgers: it had two suction pipes, one on each side. That was a very good thing. Most delays with sand-pumping were caused by accidents to the pipe and the necessary repairs. If in a sand-pump dredger with two pipes one pipe was out of service, the dredger could still go on working; she would take longer to fill her hopper, but time was spent not only in filling but also in travelling and dumping. For instance, taking the particular run from Lagunas to Valparaiso, the "Mexico" would do that in 4 to 4½ hours. With one pump working the time would be only ½ hour more; in other words, the dredger would only lose

Mr. Thomson.

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Mr. Thomson. about 12 to 14 per cent. of her efficiency; and that, of course, was much better than having her laid up. The only other matter to which he wished to refer was the fact that the breakwater throughout had had a tendency to settle towards the inner side. He thought that when the section was looked at there was not much difficulty in accounting for that. On the outer side there was a berm of rather more than 9 metres; on the inner side it was about 5 metres. Consequently the breakwater had a tendency to tilt to the inner side of the bank. With regard to Mr. Wilson's remarks about Peterhead and Valparaiso, he could not pretend to have studied wave-action as a harbour-engineer, but he had seen the waves at Peterhead and he had also seen the waves on the Pacific coast, and there was a radical difference. He could not put that difference into mathematical or engineering terms, but the waves on the north coast of Scotland were infinitely more "vicious," if he might use the term, than those on the deep Pacific coast. The very deep water close to the shore on that coast seemed to make a great difference to the effect of the waves on a breakwater.

Mr. Walsh. Mr. A. C. Walsh remarked that, having been in Valparaiso at the time when the warehouses were being constructed, he would like to call attention to the very variable nature of the ground on which they were built. They were very large structures, and on the plan in the Paper (Fig. 1, Plate 4) could be seen a dotted line crossing the site of the four buildings at an angle. That dotted line showed an old sea-wall, backed with quarry rubbish, which had been in existence for 60 or 70 years. The existence of that wall seemed to call for some form of vertical joint in the buildings, but the angle at which the wall crossed the buildings made anything of the kind too complicated. Having made a reclamation between the old and the new wall by pumping sand, which solidified immediately in quite a satisfactory manner, they had taken pressure tests on it and on the quarry rubbish behind the wall and had found that the sand was capable of bearing considerably greater pressure than was the quarry rubbish. In spite of that they had had to build the warehouses partly on the rubbish behind the wall, partly on the concrete wall itself, and partly on the pumped sand in front. It was very difficult to build a large four-storey reinforced-concrete structure under such conditions without getting settlement cracks, and he noticed in the Paper that no settlement cracks had appeared. The buildings were founded on reinforced-concrete grillages or rafts, and he thought it would be interesting if the Authors could give a few facts as to the nature of the buildings and the pressures allowed in calculating the reinforced-concrete raft, which was designed by the contractors in Valparaiso. With reference to the substructure of the breakwater, he noticed that the conclusion arrived at by the Authors was that

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very little subsidence into the clay bottom had taken place. He had been there himself during the construction of the mooring-jetty, which had a somewhat similar foundation and which ran out into about 35 or 40 metres of water. The bottom at that site being rather softer than on the site of the breakwater, they had taken pressure tests on the two to make comparisons. In the case of the mooring-jetty sudden settlements of 3 to 4 metres at a time occurred during the placing of the banks, and on those occasions they had also observed a rise of the sea-bed beyond the site of the mooring-jetty. On the mooring-jetty the total loss of the substructure had amounted to as much as one-third of the material deposited. He did not know what it had been on the breakwater extension, but he thought it must have been nearly 30 per cent., and in that case it was rather difficult to imagine where several million tons of material had gone, unless there had been considerable settlement into the mud at the bottom. It could hardly have lost in volume by consolidation, as sand formed a fairly compact mass from the time it was dropped. The Authors might, perhaps, be able to give a little more information on that point. Mr. Walsh.

Mr. ALARIC HOPE wished to ask a question as to the monolithic part of the breakwater to which the breakwater described in the Paper was joined. In the discussion on the previous Paper the late Sir Maurice Fitzmaurice criticized the design of the monolithic blockwork. He pointed out that it would receive the wave blows directly, and thought that the downrush of the water after striking the face of the breakwater would displace the blocks of the rubble foundation. Mr. Hope asked whether 10 years' experience of that part of the breakwater had proved or disproved the correctness of Sir Maurice Fitzmaurice's criticsm. In the Paper under discussion £640 per linear foot was given (p. 203) as the contract price of the 700-metre breakwater, but farther down the page it was pointed out that owing to the substitution of sand for quarry waste and other modifications that figure had been amended: the new figure, however, was not given, and the £640 did not appear to be of much use, as it did not apply. Perhaps the Authors could afford some enlightenment on that point. The explanation of the slips on the embankment was not very clear to him. No doubt it was a difficult thing to explain, but it was not clear on reading the Paper whether the substructure of the breakwater was on mud or on clay, or partly on the one and partly on the other. If the bank of sand neither widened nor lengthened when those slips occurred, they could only be due either to compression of the subsoil or to compression plus a certain amount of infiltration of mud. It would be interesting if the Authors could say by what percentage the calculated quantity of sand and rubble to Mr. Hope.

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Mr. Hope. form the substructure had been exceeded, as a consequence of the slips. The extreme end of the 700-metre breakwater consisted, as he understood, of sloping blocks, with no special strengthening except some ironwork which bound the top courses together. It could easily be seen how difficult it would be to bind the lower blocks, but at the same time it appeared to him that the wave-action might possibly displace the extreme blocks which were not tied; because they were only held there by the friction of the blocks above and below them, and wave-strokes, as everybody knew, were powerful things. Had the actual heights of waves in storms been recorded, and, if so, how did they agree with the heights assumed by the Chilean engineers who planned the works? Further, was the shelter afforded by the extended breakwater sufficient to permit ships behind the breakwater to remain tied up at the various quays when there was an ordinary storm outside? It seemed to him that the waves must come back into the sheltered portion of the harbour, and if the motion inside rendered it difficult or impossible for vessels to remain tied up at the quays, so that they had to go out into the bay as they used to do before the harbour-works were constructed, the money spent on the 700-metre breakwater could hardly be justified.

Mr. Du-Plat-Taylor. Mr. M. Du-Plat-Taylor remarked that in the Paper by Messrs. Stanton and Walsh a method of discovering the bearing capacity of the bottom was described, and it was stated that the bottom was mud and that the penetration at 165 metres from the shore into the mud with a load of $2\frac{3}{4}$ tons per square foot was 14 feet, and farther out, about half-way along the site of the breakwater extension, as much as 24 feet. It looked, therefore, as if the slips were due to displacement or compression of the mud, which, of course, would be indicated by a rise in the bottom adjoining the toe of the slope; and, like Mr. Alaric Hope, he would ask what was the amount by which the cubic measurement on the plans was exceeded by the actual quantity deposited. That question was always important in preparing any sort of estimate for a structure of the kind described. On the first lengths of the dams which enclosed the Zuider Zee, constructed of sand pumped behind banks of boulder clay, there had been a great deal of sinkage; in fact, in the first lengths from the island of Wieringen to the mainland, which carried a double line of railway and a roadway, the quantity of material which the contractor had had to put in on some sections had been as much as 40 per cent. more than the estimate. Consequently the contractor had suffered very severe loss, and for the succeeding lengths of dam the Dutch Government had undertaken the risk and had paid for the quantity of material deposited. On comparing the plan given in the Paper with that appended to the Paper by Messrs. Stanton and Walsh,

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there appeared to be a considerable difference between the North points. Possibly magnetic north was indicated in one Paper, and true north in the other; the difference was about 18° by rough measurement. Mr. Du-Plat-Taylor.

Mr. F. E. WENTWORTH-SHEILDS was filled with admiration of the idea of making a breakwater on a bank of sand, and felt very grateful to the engineers who had done it first. He did not think that many engineers would like to be the first to do such a bold thing. He was much interested in the question of the compression of the mud underneath the big sandbank which formed the base of the breakwater. At Southampton about 400 acres of land was being reclaimed by pumping sandy clay on to existing mud lands situated at about half-tide level and covered with very soft mud to a depth of 10 or 15 feet. The question how much settlement would take place on superimposing on that soft mud a mass of sandy clay about 15 feet thick was a very puzzling one. They had come to the conclusion that it was very difficult to estimate the settlement in the absence of any data. It was known, of course, that if a bank were put on sand which was already in close order the compression was practically nil, even if the sand was so fine as to be what was often spoken of as mud; but with clay the circumstances were quite different. He presumed that many members had read the very interesting articles published by Dr. Terzaghi [1] some years ago. Dr. Terzaghi had experimented on the compressibility of clay and had shown that with any given clay the application of a certain load squeezed the water out of it and caused it to shrink, but that, on the other hand, when the load was removed the water was reabsorbed and the clay swelled again. Further, that there was a definite connection between the volume of the clay and the pressure upon it. There was no doubt, from experience which had been gained on other sites at Southampton, that in a case of a mud which was of the nature of very soft clay—not a sandy mud but a clayey mud—the compression that took place on tipping a large quantity of earth on to it was very considerable; but there was no means of estimating it exactly. It seemed to him that it would not need very elaborate investigation to arrive at a formula whereby a fairly accurate estimate could be made. At the Building Research Department at Garston (Herts.) experiments on earth-pressures were being made under the supervision of Dr. C. F. Jenkin, M. Inst. C.E., who had done some valuable work on sand which it was hoped would form the subject of a Paper for The Institution. He was sure it would be of the greatest interest to members. He hoped that Dr. Jenkin would follow it up by some Mr. Wentworth-Sheilds.

[1] *Engineering News-Record*, vol. 95 (1925), p. 742.

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Mr. Wentworth-Sheilds.

work on clay which would enable engineers to settle what the compression of clay—whether in a hard state or in a soft state—would be under a heavy load. He was also much interested in the layout of the Customs Quay, which he understood was the quay with the four warehouses on it (Fig. 1, Plate 4). Apparently the warehouses were situated behind the transit sheds, and cargo had to be hoisted by the quay cranes on to bridges and run back into the warehouses on a narrow-gauge railway. Probably every engineer and every port had different ideas as to the best way of handling cargo to transit sheds and to warehouses; but it did strike him that that method involved a good deal of unnecessary double handling. It seemed that if some method of putting the cargo into a truck could have been devised—perhaps not a rail truck, but a flat-wheeled truck—that double handling would have been avoided. One other item of interest to him was the question of the cracks in the asphalt roof of those warehouses—a matter with which, he supposed, many engineers had had trouble. A large flat concrete roof covered with asphalt, even if the concrete were well reinforced, was sure to show cracks. Although asphalt was a fairly pliable material, the cracks in the concrete would repeat themselves in the asphalt. He had not yet heard of a satisfactory solution of that difficulty. Perhaps one might be found in covering the cracks in the concrete with something like felt, which would withstand a certain amount of tension; but he would be very glad to know if any member had solved that problem.

Mr. Gedye.

Mr. N. G. Gedye remarked that the breakwater at Antofagasta described in the Appendix to the Paper was built of horizontal coursed blocks, and he thought that those blocks had no bond or key in the horizontal planes. When Sir John Wolfe Barry and Sir William Matthews reconstructed the outer half of the North Pier at Tynemouth [1] between 1901 and 1908 they introduced a measure of horizontal bonding of the coursed blocks which he believed was then novel and of which he thought the Tyne Pier was the first example (*Fig. 7*). A check, 6 inches high, extending practically from end to end of the work, was provided in each course of blocks below low water, with the object of preventing the sliding of one course of blocks over the course immediately below it. The blocks above low water were set with cement joints and beds. He would like to know whether, in the Authors' opinion, if the breakwater at Antofagasta had had the courses bonded as in the Tyne Pier, the disaster would have occurred. As to the depth to which sea-action extended, the North Pier at Tynemouth was constructed in a depth of approximately 35 feet at low water of spring tides, or about 50 feet at high water. In making an examination of the pier in diving-dress about

[1] Minutes of Proceedings, Inst. C.E., vol. clxxx (1910), p. 133.

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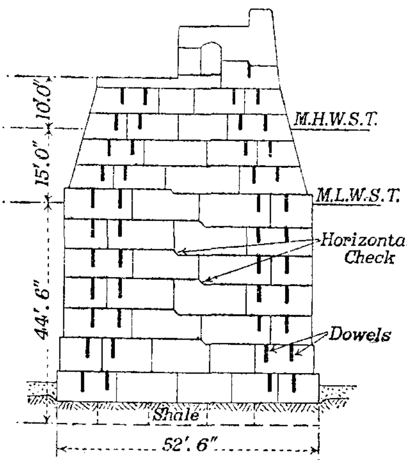
the year 1911 he had walked round the breakwater head and had found on the sea-bed, a few feet away from the wall, a number of large photographic plates, most of them undamaged, some of which he had recovered. They had been identified as plates used by the resident engineer on the work and thrown overboard when the work was finished, 3 or 4 years before he discovered them. His observations of the piers at the mouth of the Tyne showed that at a depth of 35 feet below low water there was no serious wave-action. The difference between the waves on the Pacific coast of South America, as at Valparaiso, and those on the east coast of England and Scotland, Mr. Gedye.

Fig. 7.



to which Mr. Wilson had referred, might be due to the difference in the depth of water near the shore. The waves that rose against the face of the outer part of the breakwater at Valparaiso in a great depth of water were almost waves of pure oscillation, whereas on the shallower east coast of England and Scotland the waves were, he thought, largely waves of translation, even in the comparatively deep waters at Peterhead or at the mouth of the Tyne.

Sir John Thornycroft. Sir JOHN THORNYCROFT asked whether any consideration had been given to the earthquake conditions. Valparaiso had more than once been badly damaged by earthquake. He had happened to be there shortly after the last serious one, and had seen some reinforced-concrete buildings which were standing while the majority of the others were destroyed. He wondered whether any special considera-

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Sir John Thornycroft.

tion had been given to the effects of earthquakes in connection with the design of the breakwater.

Mr. Wilson.

Mr. MAURICE F.-G. WILSON, referring to Mr. Gedye's remarks about photographic plates lying undisturbed on the rubble mound, said he could give another somewhat similar instance. He had already mentioned a breakwater built without transverse bonding, where the outer row of blocks fell outwards due to undermining. It had been stated that there was no fear of any undermining by the downward stroke of the waves occurring, because some shovels which had been left by a diver at the bottom through a whole winter season had not been disturbed. Nevertheless, the breakwater had failed subsequently, due to the undermining of foundations on the seaward side.

Dr. Brysson Cunningham.

Dr. BRYSSON CUNNINGHAM thought that Sir Francis Spring's description of Madras harbour as "a gauntlet flung in the face of Nature" could be still more aptly applied to the breakwater at Valparaiso, because apparently the conditions there from an engineering point of view were even more adverse than those found on the east coast of India. It was an extremely exposed situation, subject to storms of terrible violence, with a great depth of water—unprecedented, in fact, for the purpose of a breakwater—with an unsound and unsatisfactory foundation, a configuration of the coastline which was quite unsuitable, and, to crown all, a liability to earthquakes. He did not think a combination of circumstances worse than that from a harbour engineering point of view could be found anywhere, and he quite agreed that Sir Ernest Moir was entitled to every credit, in conjunction, of course, with the Chilean engineers, for having tackled the problem in so successful a way. Having no knowledge of the local circumstances, he had some hesitation in putting forward a comment which had occurred to him. It seemed from the Paper that some reassurance was derived from the fact that the line of the breakwater was oblique to the direction of the heaviest waves. While that might obviate difficulties at the breakwater itself, due to the breaking of the waves, it served merely to divert the trouble by passing the waves on in the direction of the shore. The essential function of a breakwater was to break waves, or better still, if it could be done in sufficiently deep water, to reflect them; but the deflection of the waves was another matter altogether, and it seemed to him that waves passing along the line of the breakwater would still retain their disruptive force, and might even pass, as often occurred round headlands, into what was supposed to be the sheltered area inside. Had any such effect been experienced? He was sorry to gather from Sir Ernest Moir's remarks that no observations had been made of the actual stroke of the waves on the breakwater. There seemed to have been abundant opportunities, in the 15 years or so during which the

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works had been under construction, for making such observations, and information of that kind would have been of great value to engineers. Dr. Brysson Cunningham.

The AUTHORS, in reply, remarked that they believed that neither at Antofagasta nor at Valparaiso was there any very great amount of horizontal movement in the waves striking the breakwaters (except on the inshore portions, where the 60-ton wave-breaker blocks efficiently destroyed their force). That view, they believed, was supported by the fact that in the damage to the uncompleted work, which occurred in 1928, whilst the blocks on the inner edge of the breakwater were moved by the hydraulic force of the falling masses of water, the outer course, exposed to whatever wave-stroke there might have been, remained undisturbed. At Antofagasta there had been no gradual battering away of the wall but one long portion had disappeared in a few seconds, followed by the rest after an interval of a few hours. Moreover failure took place at the lowest horizontal joint and not near the surface where the effects of wave-stroke would be at a maximum. The relative absence of wave-stroke on deep structures built in the Pacific ocean probably accounted for the greater immunity of their foundations from the effect of scour. During storms in Valparaiso the one-man rock, used for levelling up the foundation for the blockwork, had been occasionally removed round the scar end, that was, at a depth of 40 feet; on the other hand, sand deposited up to depths of 60 to 70 feet at a distance of at least 200 metres ahead of the blockwork had remained undisturbed. Soundings taken a few years ago in front of the monoliths of the first section of the breakwater indicated that there had been no disturbance of the apron blocks, and as regarded the rubble bank the lower part appeared to have shoaled, having presumably acted as a trap to the small amount of sand travelling round the bay. The price of £640 per foot quoted in the Paper for the new extension just completed referred to the modified form of breakwater as contracted for; the later modification, involving the flattening of the slopes, had not affected the contract price. As to the big slips which occurred in the mound during the early days, the investigation described in the Paper had led to the conclusion that the sudden movements were due to the sliding of the toe of the bank on the surface of the clayey mud composing the sea bottom, which was not accompanied by any appreciable upheaval of the latter, or penetration of the sand into the mud. Apart from that, however, there was a large loss of material unaccounted for. The proportion of material lost increased continuously as the work progressed out into the centre of the bay and averaged 57·5 per cent. on the quantities calculated from the plans. Part, no doubt, had been lost by dispersion in dropping through the great depth of water; but that cause alone could not account for anything The Authors.

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The Authors. approaching the total loss, and it seemed certain that there must have been considerable compression of the clayey silt forming the sea-bed, especially towards the outer end of the mound. That compression, no doubt, would decrease towards the toe of the bank, where the borings had been made, and would increase gradually as the weight was applied. Very heavy storms only occurred at considerable intervals, and nothing had been experienced during the construction of the breakwater extension to compare in intensity with the great storm of July, 1919. Satisfactory measurement of the height of storm waves, the worst of which frequently occurred at night, was very difficult, if not impossible, and no records had been kept at Valparaiso. Since the work described was nearing completion ships had always been able to remain at their berths inside the harbour in any state of the weather. The waves did not run round the head of the work to any extent, probably due to the almost vertical shape of the end of the wall, but complaints had been heard, from the owners of lighter-moorings situated outside and beyond the outer end of the breakwater, that the effects of the seas on their areas had been intensified by the action of the new works. The Authors agreed with Mr. Wentworth-Sheilds's suggestion that flat-wheeled trucks might have been adopted for the distribution of merchandise to the warehouses; they would go even farther and believe that in future, except perhaps for heavy bulk trade, the tendency would be for railways to disappear altogether from the dock side and for their place to be taken by roads suitable for the use of self-propelled trucks. It must be remembered, however, that this particular layout was originally designed about 20 years ago. In practice, moreover, the tracks were quite satisfactory on the bridges, as on entering the warehouses they were discharged for the purpose of checking the weight of each package. All the courses of blockwork in the Antofagasta breakwater were provided with horizontal joggles of similar type to those mentioned by Mr. Gedye, except the joint on top of the foundation course exactly where the failure took place. On that joint the angle of friction due to the combination of the weight of the upper courses and the thrust due to a mass of water, level with the parapet on the sea side, approached the limit for sliding of concrete on concrete. As far as the Authors were aware no special consideration had been given to the effects of earthquake in the design of the breakwaters. It was unlikely, except possibly for a little extra settlement, that earthquakes would have any effect on the structure, as it was virtually founded on a raft floating on the mud of the sea-bottom. They had little doubt that the discrepancy in the plans to which Mr. Du-Plat-Taylor had drawn attention was due to the cause suggested by him. The magnetic declination at Valparaiso was about 15 degrees.

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