Discussion.

ıe President. The PRESIDENT, in moving a vote of thanks to the Authors, remarked that the importance of the four Papers really lay in their treatment of the problem of wave-reduction. In one of the Papers important details of construction were described, as well as dredging and other things; but it appeared to him that it would be better to restrict the oral discussion, as far as possible, to the formation of harbour-works with the view of reducing wave-action. It would still be quite open to any member to contribute in writing to discussion of the Papers from the point of view of contructional details. That course would assist to concentrate attention on a problem of the greatest interest to those who had devoted their lives to harbour-work, a problem that had received very little consideration since the days when Mr. Stevenson brought it forward in his book on harbours.[1] There was danger, of course, in generalizing; but it was fortunate that all the Papers dealt with works situated on the same coast, and subject to similar conditions, so that they could safely be discussed together.

Mr. Mitchell. Mr. MITCHELL exhibited a number of slides showing wave-action in connection with Whitby Harbour, and Mr. SIMPSON presented slides illustrating Sunderland Harbour.

Sir Whately Eliot. Sir WHATELY ELIOT observed that there was similarity between the four harbours to the extent that they were all situated on the north-east coast of England within a few miles of each other, and they were all in very exposed positions; but there, he thought, the similarity must end, because the natural positions of the harbours differed. At Blyth and Whitby the enclosure of large areas to intercept and flatten the waves was precluded; in fact, at Blyth the entrance was naturally so contracted that very little could be done in that way, and therefore what had been done was inside. During the last few days he had referred to some old charts which he happened to possess, showing the various harbours along the coast in 1750, and the state of their entrances at that time was rather interesting in comparison with what it was now. At Sunderland there was then on the bar 2 feet at low water and 9 feet inside.

[1] T. Stevenson, "The Design and Construction of Harbours," 3rd ed. Edinburgh, 1886.

Sir Whately Eliot.

In those days the ships entering the harbours were very much smaller than they were to-day, but still the state of affairs then could be imagined. Any vessel arriving about low water had to remain outside until there was enough water on the bar for her to come in, and that must have been very risky. At the Tyne there was on the bar in those days 7 feet of water, in comparison with the present 30 feet. At Blyth inside the harbour there was only 6 feet of water and 2 feet on the bar, and he believed it was then possible at times to walk across the mouth of the harbour. He did not know much about Blyth or Whitby, but he happened to have been engaged in his younger days on the construction of one of the docks at Sunderland and also of the Tyne piers. It seemed that works constructed to reduce wave-action inside a harbour, and to improve the entrance for ships entering the harbour, were so interdependent that they ought to be carried out one with the other. He had an object-lesson as to the desirability of protective works outside the Tyne when he was there, as he witnessed one day the most pitiable wreck he had ever seen—and he had seen a good number in his time. A sailing ship was entering the Tyne, before a gale of wind, with a very strong ebb-tide; it was so strong that the ship lost steerage-way when opposite that part of the piers where they set outwards, and broached to; and it only required two or three of the big seas inside the piers to break her to pieces. He also saw a very bad wreck on the Black Midden Rocks inside. That showed that the Tyne was a very dangerous spot in rough weather before those splendid outside piers were built. He thought the work that had been done, especially at Blyth, was most ingenious. The two piers at Whitby looked on the plan rather a curious arrangement, but evidently, from the photographs which had been shown, they had had a good effect, not only in flattening out the waves but also in leading them to a space where they could be dispersed.

Mr. C. S. Meik.

Mr. C. S. MEIK remarked that he approached the subject referred to in the Papers with pleasure, because Sunderland happened to be his native place. The four harbours referred to were typical of the east coast, and the more important of them were those of Sunderland and the Tyne, which he regarded as harbours correctly designed in every respect. It must be recollected that the first thing in a harbour was to allow shipping to get in, and the next thing was to keep the sea out as much as possible: it was useless to keep the sea out unless the shipping could get in. He was sorry to say there were a good many harbours in this country, more especially in Scotland, which were so successful in keeping

Mr. Meik. the sea out that ships could not enter in a strong gale. At both the Tyne and Sunderland, however, there was access at all times and in all weathers. Comparing the entrance to the Tyne with the entrance to Sunderland, it would be noticed that the former faced almost due east, so that easterly seas came full into the harbour, whereas at Sunderland the entrance faced south-east and—he did not go so far as to say that this was a defect, but only pointed it out—any vessel entering Sunderland Harbour in a north-easterly wind had a cross sea. In his opinion Sunderland was not such an easy harbour for access as the Tyne, since with a flood-tide there was a cross-current as well as a cross sea to contend with at the entrance. The same question had arisen lately in the discussion on the harbour at Dover,[1] where there was a cross-current which rendered that harbour not too easy of access at certain times. He noticed that Mr. Simpson gave the width of entrance at Sunderland as 700 feet, whereas at the Tyne it was 1,200 feet. Both those entrances were on the full side, and he would have been inclined in the case of Sunderland to adopt Sir John Coode's width of 500 feet. In the old days when sailing ships were universal he would certainly have said the widths that had been fixed were not too much, but in the present day of steamships they were on the full side, and he thought they might have been reduced with advantage, so reducing the amount of swell getting into the harbour. With regard to the original state of Sunderland Harbour, Sir Whately Eliot had referred to a chart of 1750, and it was curious that that was the date at which the first pier was constructed at Sunderland, namely, the south pier, which was commenced, in 1750, under the headland which was then just below the barracks marked on Fig. 1, Plate 5. That pier was constructed by an engineer named Robert Shout: Smeaton was consulted shortly after it was commenced, but he did not appear to have recommended what would now be considered absolutely necessary, namely, the construction of a north pier. That pier was begun in 1786 by the same engineer, but was not the north pier that existed now, which was Rennie's. In 1807 Jessop recommended that a new north pier should be made, as well as an alteration in the south pier. Jessop designed his harbour on correct lines, with converging piers, but his proposal was not carried out. Subsequently Rennie's design, which showed parallel piers, was adopted and carried out so far as the north pier was concerned. It would be noticed on the plan that the inner piers were not parallel but slightly bell-mouthed,

[1] *Ante*, pp. 76–97.

the worst shape possible for a harbour on the east coast. John Murray rebuilt the north pier in 1832 and extended it, and he also rebuilt the inner part of the south pier and altered the shape. Mr. Meik had in his office a painting by Carmichael, dated 1847, showing the reconstruction of that pier, which was completed by his father after Murray had severed his connection with the River Wear Commissioners and had become the engineer to the Sunderland Dock Company. It would therefore appear that Murray was responsible, more or less, for the bell-mouth shape of the inner entrance. Murray completed and extended Rennie's north pier, but Mr. Meik did not think he finished it on Rennie's design, because part of the masonry work was founded on piles, although the rock was near the surface. The piles always gave trouble in the fifties and sixties of last century, and Mr. Simpson had apparently found them a very serious source of difficulty. It was to be regretted that the Commissioners, after spending so much money on the fine outer piers, did not reconstruct the two inner piers, completely altering their shape and making them converge with a smaller entrance between their outer ends. It would be seen that at Sunderland there were two entrances, the north or main entrance, and the south outlet. The latter ought never to have been constructed. Its existence was due to the fact that, at the time the Dock Company got their powers, the River Wear Commissioners were a retrograde—not to say obstructive—body. At that time, about 1846 to 1850, there were no less than 170 of them, but fortunately not all of them qualified, so that the acting body of Commissioners at that time was really between fifty and sixty. The Dock Company, which was composed of commercial men who knew what they were about, were very anxious to get the needed depth of water, but they could not interfere with the entrance to the harbour, as it was under the jurisdiction of the Commissioners. They therefore got powers to construct the south outlet, which for many years was the chief entrance to Sunderland, as it had a greater depth of water than the northern entrance between the old piers. There were one or two points with regard to the Tyne to which he would like to refer. Mr. Hindmarsh pointed out that things had changed, since Thomas Stevenson wrote his book on the design and construction of harbours, mainly in regard to the depth of water and the size of vessels; but there was more in it than that. When Stevenson wrote his treatise the sailing vessel was in great use, and the change to steam had altered the whole of the conditions with regard to harbour-entrances. Some of the harbours on the East Coast would have been derelict at the present day had

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Mr. Meik. not steamships come into use. With a strong north-easterly wind it was impossible for a sailing ship to enter Blyth harbour; in order to do so she had to go broadside to the wind, and that meant being driven ashore. For that reason, in a north-easterly wind sailing ships never went to Blyth; they put into the Tyne instead. Steam had altered that, and Blyth was now one of the successful harbours on the East Coast, with a very large shipment of coal. With regard to the Tyne, Mr. Hindmarsh said: "Waves of the same height at the pier-ends have been correspondingly reduced to 4 inches at the same point up the harbour under similar conditions of tide, but with wind from the westward (i.e., from landward)." It would have been thought that with an off-shore wind there would be no sea at all, as with an off-shore wind on the East Coast the sea was practically negligible. Mr. Hindmarsh also referred to the great improvement which resulted from James Walker's plan of commencing the north pier from the north side of Prior's Haven. That had been the salvation of the Tyne. If the north pier had been under the Battery headland the whole of the sea would have run up into the entrance of the Tyne, and the state of matters in north-easterly gales would have been impossible. Perhaps Mr. Hindmarsh would be kind enough to give the height of the waves observed at the time, as that figure did not appear in the Paper, and many different opinions had been expressed as to the height of waves in a north-easterly gale. Most engineers would agree with Mr. Sandeman's suggestion that the term "range," in connection with wave-action, should be applied to the movement of waves entering a harbour from the sea. At the same time, although "range" had been adopted as an engineering, and possibly as a nautical, term, he thought it had been misapplied, because in the nautical sense "range" had to do with the length of cable that a ship let out when anchoring, and not with the height of the sea. Nautical men, when they spoke of the height of the sea, used the word "send." When a vessel sended she rose through a certain height which represented the distance between the hollow and the crest of the wave. Send was the more appropriate term to apply to the vertical height of the waves than the word range. He thought he was right in saying that "range" was not used by Stevenson in his book; he called it "run" where he spoke of seas entering a harbour. Mr. Sandeman went on to say: "When propagated into a harbour through a deep entrance-channel, waves do not break, and although their height rapidly diminishes, their velocity and momentum are only gradually quelled by the reaction of still water

within the harbour. During the reduction of waves in this manner, they are, of course, changed from waves of oscillation to waves of translation, which lift and move the heaviest ships, although the range wave may not exceed 12 inches in height." He understood the Author to mean that the waves did not change from oscillation to translation until they entered the harbour, but he believed that such was not the case, because in a heavy gale on the Tyne or the Wear the waves were already waves of translation before they entered the harbour, and it was when they had changed to waves of translation that they did all the damage. A wave of oscillation in contact with a pier in deep water did not affect it to anything like the extent that a similar wave of translation would. He could not agree with Mr. Sandeman that a 12-inch "range" would move the heaviest ships; that seemed to be an exaggeration. With regard to Sunderland, it was only right he should add that the Commissioners were reconstituted subsequent to the time of which he had spoken. The constitution was altered in 1859, and the Commissioners were now a truly representative body, although their number, fifty-two or fifty-three, was too large for a workable body, and contrasted strongly with the thirty-two Commissioners who dealt with the Tyne. He had omitted to state that the south outlet at Sunderland was only 235 feet in width. Before the new piers were constructed, in 1890, all large vessels went through that entrance into the docks, as there was not sufficient water at the other entrance; and they entered at all times except on the few days in the year when there was a heavy north-easterly gale blowing. The new entrance was 700 feet wide. It was true that vessels were bigger to-day, but there was a great difference between those widths. That was one of the arguments on which he based his opinion that 700 feet was too wide. His old friend, Mr. Henry Wake, was mainly responsible for designing the piers and carrying them almost to a very successful conclusion, and Mr. Simpson had had the good fortune to finish them. Mr. Wake's career was unique in a way, for he was born, educated, and trained as an engineer at Sunderland, and he carried out there one of the most successful harbours constructed on that coast—or indeed anywhere.

Mr. Meik.

Sir William Matthews.

Sir WILLIAM MATTHEWS, K.C.M.G., Past-President, remarked that there was a great advantage in considering in a group four such Papers as those before the meeting, and he thought the discussion of them should elicit valuable information on the question of range. Mr. Meik had already referred to that matter. He thought Mr. Sandeman's words, as given in his Paper, conveyed a terse description of

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"range," and in spite of repetition he would quote them:—"The term 'range,' when applied to wave-action, should be confined to the movement of waves entering a harbour from the sea." Not long ago he had occasion to refer to waves of a different type, what Mr. Hindmarsh called a "jobble," and naval men called a "windlop." The extent of the range depended to a large degree on the disturbance in the offing. When he had the honour of occupying the position which his esteemed friend, Sir John Griffith, now held, he prepared, in connection with his Presidential Address, certain particulars bearing on harbour-construction—a branch of work which had been the means of supplying him with bread and butter since he entered the profession—and among the questions dealt with was that of the height of waves at different ports. It was not easy to determine the height of a wave accurately. He had had a good deal of experience of engineering work at the mouth of the Tyne, where his firm had had to rebuild about 1,400 feet of the north pier that had been badly damaged, and he had also had some important matters to deal with in connection with the disturbance by range in the lower portion of the Tyne; consequently he was acquainted with the subject of the Paper submitted by Mr. Hindmarsh. At that time his firm were anxious to obtain information with regard to the height of the waves in the offing near the Tyne entrance, and they arranged with Mr. Barling, their resident engineer, to take observations of the oscillations of the buoy to the east of the south pierhead. The resident engineer, stationed with a theodolite at the base of the north pier, took observations there on different occasions when bad weather prevailed, and the conclusion he arrived at was that the height of the waves at the entrance to the Tyne varied in bad weather between 32 feet and 40 feet from crest to trough. That looked almost an exaggeration, but he could mention in confirmation that at Peterhead, which was the most exposed place he or his chief, Sir John Coode, had ever had to deal with, similar observations were made by taking sights across the bay, and it was found that, with seas rolling in from outside, there were waves measuring 40 feet from crest to trough. That was the highest wave-disturbance he had ever come across in his professional work. He believed Mr. Hindmarsh had obtained some results which were not so large. He had no reason to suppose that Mr. Barling exaggerated at the Tyne, or that Mr. Hill exaggerated at Peterhead, but their figures were considerably in excess of what had been believed to be the heights of waves in bad weather. With regard to Mr. Sandeman's description of disturbance coming in from the outside, the Tyne, the Wear, and the Blyth all dis-

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charged along a stretch of the Northumberland coast little more than 40 miles in length, so that the waves in the offing were very much the same, although they were affected by the changes in depth as they approached the shore. There must be at the Tyne, and at the Wear, and also at Blyth, considerable undulations passing in through the entrances, and therefore a considerable range within the harbour. The question arose, what was the best method of overcoming that difficulty? He had seen many attempts to do that, and his own opinion, based on experience, was that it could only be accomplished by well-arranged and extensive spending-beaches. Farther up the rivers, where the waves became concentrated, wave-traps and other minor devices might be used, but the main reduction of the range must take place at the entrances, by means of adequate spending-beaches. Looking at the plan of the entrance to the Tyne in Mr. Hindmarsh's Paper, it would be seen that opposite South Shields there was really a splendid spending-beach, which broke up the waves. From the fish-quays at North Shields right away to Prior's Haven at the base of the north pier, there was another spending-beach; and he had but rarely seen a better combination of spending-beach and rocky foreshore. The seas coming in broke against the rocky shore, and were also absorbed in Prior's Haven; they were whirled on to the cliffs at the Spanish battery and Black Middens, and dispersed to a large extent in the area marked by dots in Fig. 1, Plate 3. He had been in one or two very stiff fights in connection with the proposal to place a fish-dock right on that spending-beach, which the Tyne Commissioners had been successful in preventing. If at some future time any attempt were made to interfere with the action of the north spending-beach and the cliffs and the Black Midden rocks in any way which would reduce their efficiency or interfere with their breaking-up powers, it would be a very bad day for the wharves and the many commercial undertakings in the lower portion of the Tyne, because it would certainly result in the transfer of the undulation farther up the Tyne. He held no brief for the Tyne Commissioners—indeed his days for briefs and fighting were over—but he hoped that nothing would occur to prevent the proper utilization of that splendid length of foreshore. With regard to the River Wear, which he knew very well, having been at the time Sir John Coode's chief assistant, he agreed with what Mr. Meik had said with regard to his friend, Mr. Wake, one of the best of men and a good engineer. Mr. Wake designed the Roker pier, and also an extension of the old south pier, and got the Commissioners to consult Sir John Coode. Not much progress had been made with the Roker pier before it became evident that it would be a mistake

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to carry out the new south pier as a continuation of the old pier, because the extent of the wave-disturbance coming into the Wear was such that it would be carried by the proposed pier directly between the two existing piers and into the swinging-basin. If Mr. Wake had done nothing else but propose that the new pier, which was at first intended to start from the old south pier end, should be carried 500 yards farther south, he would have deserved the highest praise from the Wear Commissioners. It could be seen that two splendid wave-basins or spending-beaches were provided, and that was the proper way to suck up any range which might pass in through the entrance. He would not go into the question of the details of wave-traps. Mr. Simpson's description of the effect of a wave entering between the piers and breaking on spending-beaches inside was well worth perusal, and he recommended young engineers carefully to consider what Mr. Simpson said. The width of the entrance of the Tyne was 1,200 feet, and it might be asked why the range could not be reduced by making the entrance narrower. When his firm were engaged in the rebuilding of the 1,400 feet of the north pier, they had occasion to go into that matter, so as to fix the point of termination of the outer end of the new north pier, and they found that, owing to the filling of the Tyne Harbour from the sea and the cross currents which were induced, it would not be safe to curtail the width of the entrance. Moreover, in these days ships were developing so much in size that a wider entrance was really more necessary than it was some years ago. On that account he thought a width of 1,200 feet should be maintained there, and therefore such disturbance as was due to the passing of waves through an entrance of that width must be dealt with within the harbour, and measures must be adopted to deal with it accordingly. That made it all the more important to maintain the spending-beaches. Mr. Hindmarsh had referred to the slope of the beach opposite Shields as being 1 in 30. He had had opportunities of observing the wave-slopes after storms on the beaches at Brighton and Hastings. His information was accurately procured, and the results came out at 1 in 10 to 1 in 12 after storms, which were very different slopes from 1 in 30. There were much heavier seas on the north-east coast than on the south coast, and, further, when the coarse shingle and sand of a south-coast beach was well pounded by the sea it formed a hard surface almost like a turnpike road. The beach at the mouth of the Tyne, on the other hand, consisted of soft sand, and it was therefore to be expected that it would form a flatter slope than a south-coast beach. Mr. Sandeman referred to the possibility of using pell-mell

blocks to absorb the range. He did not see how that method could be applied to the Tyne or the Wear. In awkward re-entrant angles and in corners where waves sometimes became concentrated, pell-mell blocks would effectually disperse them. The blocks he had used generally were about 40 tons in weight, and if such blocks were employed, and the cube was taken due to the mass of the mound including voids, and one-third was allowed for interstices, a result would be obtained, in solid concrete, practically agreeing with the cube actually used. Not long ago his firm finished a work, 2,500 feet in length, of 40-ton pell-mell blocks, and as far as he knew only one of those blocks had been lifted to any serious extent. That was a block which was lifted bodily 7 feet, carried forward, and dropped on to a block in the rear of it. He examined the block carefully but could not account for the incident. There must, he thought, have been some combination of concentrated air-pressure or wave-action to cause that block to be moved. Sir William Matthews.

Mr. J. MITCHELL MONCRIEFF felt that the members would endorse what Sir William Matthews had said as to the grouping of the Papers, which described four harbours all on one stretch of coast and all under very similar conditions, and yet all essentially different in their characteristics. There was one feature about the harbours which he thought should be kept in mind in discussing the Papers, and that was the great difference in their size; there was a 1,200-foot entrance at the Tyne and one of 170 feet at Whitby. Those two harbours illustrated very clearly and definitely two entirely different principles which were in their way perfectly applicable to the different circumstances. It was now about 60 years since Thomas Stevenson wrote in his book that probably it was much more difficult to design a small harbour than a large one, and indeed, when a harbour became very large many of the difficulties which afflicted the designer of the small harbour disappeared; and he thought that was quite true. There were various difficulties always confronting the harbour-engineer, probably more than any other kind of engineer. He never got a clean sheet of paper on which to sketch out a harbour; old works were always there already and spoilt his job. Then there were financial considerations, which in the case of a small harbour might prevent the work altogether. He had the greatest admiration for the Tyne entrance; he had known it since he was a youngster. Forty years ago he used to go down whenever there was a storm to watch the waves, and also to see what he confidently expected—wrecks. In any big storm there were almost invariably wrecks. That was long before the piers were completed. He had seen as many as six or eight important vessels Mr. Moncrieff.

Mr. Moncrieff. on the Herd sand and on the south side of the south pier at one time. He entirely agreed with Mr. Hindmarsh in his hope that the Black Middens would not be covered with a dock, as that would be a serious thing for the River Tyne. The Wear was also a magnificent harbour. He found that the amount of wave-reduction that had been obtained, according to Mr. Simpson's figures, came out at almost exactly what Thomas Stevenson would have predicted from his formula. Mr. Simpson said that a 15-foot wave at the mouth of the north entrance was reduced 5 or 6 feet between the two old piers; and by using Stevenson's formula Mr. Moncrieff obtained 4 feet 9 inches, which he thought was sufficiently close agreement. At Sunderland the south entrance was not a harbour but a dock-entrance protected by piers. The same description applied to Seaham where, in November, 1919, a south-easterly storm tore the gates right off, both the storm gates and the inner gates, which emphasized what Mr. Meik had said as to the violence of the storms on the north-east coast. If by some device, such as Mr. Sandeman referred to, it were possible to get rid of some of the troubles in small harbours, it would be of enormous value. One thing that was very striking about Blyth and Whitby was that the result had been achieved with very small means. The opening between the new pier and the old pier at Whitby looked very small to let out a large volume of water, and yet it apparently did it. He had seen at Whitby waves rolling right up the harbour before the new piers were constructed, and he was glad to hear that the harbour was now completely tranquillized. He would like to know what was the height of the waves at the mouth of the harbour at Whitby, and to what they were reduced at a certain point in the harbour. The same remark applied to Mr. Hindmarsh's Paper. Mr. Hindmarsh referred to "a certain point" in the harbour, and Mr. Moncrieff would like to know definitely where that point was. Seaham entrance was an almost exact reproduction to a smaller scale of the north entrance to the Wear, and whatever wave-action took place during storms at Sunderland would be reproduced almost exactly at Seaham, apart from any interference due to shallower depths and causes of that kind. With regard to Mr. Hindmarsh's remarks about the avoidance of reflected waves, he did not think that was appreciated in many cases, and it was a very difficult thing to prevent in a small harbour. Internal and irregular obstructions in the interior of harbours should be studiously avoided, as they produced serious reflection of waves. Both Sunderland and Seaham harbours were full of obstructions, which were the cause of great commotion inside the harbour. The

Mr. Moncrieff.

question of reflection came in, especially in connection with the south entrance. The waves which ran parallel to the north-east pier and at right angles to the south-west breakwater were simply reflected waves; and that fact was easily shown by means of a model. Models were extremely useful in the investigation of this subject, and much valuable information could be obtained from them about the movement of waves—not the intensity but the direction in which they moved. He had found also that the shape of the waves as they entered a model harbour was exactly the same as the shape of the waves that came into the actual harbour. He knew of only one other harbour in which there had been anything like the attempt Mr. Sandeman had made to cut off a piece of the incoming waves, and that was West Hartlepool, which he believed was the first example of the kind, 38 years ago. Mr. Sandeman had developed the idea very considerably and had given a great deal of attention to it, and it was always in his mind that that was the way to deal with small harbours of that kind. He would like to see more definite figures recorded for reference, in regard to the reduction of waves in small harbours.

Mr. Gedye.

Mr. N. G. GEDYE remarked that what Sir William Matthews had said about the Tyne entrance could not be emphasized too strongly. For 5 years he had had a good deal to do with the harbour of the Tyne, and with the question of range and the spending-beaches. The presence of the broad beach on the north side of the harbour, inside the Black Middens and the Herd Sand on the south side, was the saving grace of the entrance. If any curtailment of those areas took place, it would undoubtedly make the passage of the Narrows at Shields and the berthing in Shields harbour much more difficult and dangerous than they were. The works that had been carried out might be regarded as fairly effective at the present time in reducing range with the existing depth of water at the entrance, namely, 30 feet at low water. If at any time further deepening to 35 feet or more in the entrance-channel took place it was quite possible that some further works for the prevention or reduction of wave-action in the harbour might be necessary. The wave-trap on the south side of the Narrows marked "B" in Fig. 1, Plate 3, might be enlarged, and possibly the engineers who had charge of the works might find some additional means of reducing the wave-action. During north-easterly gales seas rebounded heavily from the inner face of the south pier where the bend was. He had frequently observed the course of waves rolling into the inner harbour deflected from the face. The curious form of the south pier was due to the history of the two piers. They were originally

Mr. Gedye. intended to terminate in much shallower water, nearer the shore; but, when half built, the south pier, like the original north pier, was deflected outwards, causing a rather ugly curve, which certainly led the sea, under certain conditions of wind, towards the inner entrance. A spur built out from the inner face of the south pier might be one means of still further curtailing the range, if that were found necessary on account of further deepening of the harbour channel. Mr. Simpson gave figures showing the ratio between the width of the entrance and the area of the harbour at Sunderland as 1 foot to 0·184 acre. Comparing that ratio with a few other harbours of similar character, the Tyne Harbour, with an area of 410 acres, and an entrance width of nearly 1,200 feet, had a ratio of about 1 foot to 0·35 acre; Seaham Harbour, which it was practically impossible to enter in heavy weather from the north or north-east, had a ratio of 1 foot to 0·1 acre, the spending-area being very small; Peterhead, which was about 331 acres, had a ratio of approximately 1 foot to 0·21 acre. The Tyne had gained a great advantage by the wise forethought and judgment of Mr. James Walker, when, in 1853, he included Prior's Haven within the harbour-area. The general planning of that harbour, which was designed mainly by Mr. Walker, before 1853, was substantially what any experienced harbour-engineer at the present day would lay down, in spite of the great change in conditions in regard to size of ships and substitution of steam for sails. He did not think the site of the north pier as it now existed would have been materially changed had Sir William Matthews, or any other competent engineer of the present day, had a free hand in settling where it should be built. The same applied to the south pier, with the exception of the ugly bend in it, which he had no doubt any engineer nowadays would try to avoid. On the question of range, Mr. James Walker the second, Mr. Gedye's immediate predecessor at the Tyne, started a very elaborate and valuable series of range observations, by a method which Sir William Matthews had described; and he believed those observations had been made regularly on all occasions when there was any sea exceeding waves of a few feet at the entrance. A complete series was taken, both at the south pier buoy and the north pier buoy, in every case by angles measured from the lighthouses on the pier-heads. Similar readings were taken on the Herd Buoy on the south side of the channel and by gauge readings at various points on the south side and on the north side of the Narrows entrance. It would be of interest if Mr. Hindmarsh could give some figures showing the reduction ratio for heavy seas exceeding a certain height at the entrance due to north, north-easterly, and easterly winds

respectively, with the corresponding reductions at one or two points at the mouth of the inner harbour. The Wear Commissioners were certainly to be congratulated on the fact that the proposal made in 1876 to construct the new south pier as a continuation of the old inner south pier was abandoned. With the depth of water Mr. Simpson had obtained in the harbour Mr. Gedye was afraid that if that pier had been constructed the entrance would have been an impossible one, and the River Wear Commissioners owed a great debt of gratitude to Mr. Wake, who, he believed, settled the plan of the new south pier. The nearest parallels to the curious, and apparently very efficient, wave-traps provided by Mr. Sandeman at Whitby were to be met with on the French coast. On the northern coast of France there were many small harbours in which little wave-traps were to be found in every conceivable position along the sides of the entrance channels. Nearly all the entrances to ports on that coast, from Dieppe to Ostend, were long narrow channels between timber and concrete piers—works broken here and there by little wave-traps and small spending-beaches; and there were many examples of the useful effect of such traps and beaches, which in effect were somewhat similar to those at Whitby. The way in which the gaps between the old and new piers at Whitby had apparently been effective in reducing and checking the propagation of range up the harbour was extraordinary. The travel of beach on the north-east coast was from north to south, and usually there was an accumulation of littoral drift material on the north side of a projection from the coast, and a loss of beach and consequent erosion on the south side. At Sunderland the erosion of the foreshore to the south of the South Outlet was serious, and had it not been for the presence of a wide stretch of rocky "scar" on the foreshore at Hendon near low water, he thought Mr. Simpson's troubles on the south side of the South Outlet would have been very much more serious than they were. At the Tyne entrance the safeguard to the back of the south pier was the presence of a small headland known as the Trow Rocks, more than ½ mile to the south, the rocks of which formed a natural groyne and trapped sand and shingle between it and the south pier, thus safeguarding the latter against erosion on its lee side. Mr. Gedye.

Mr. JAMES MITCHELL in reply, thanked the members for the kind reception they had given to his Paper, and particularly those who had taken part in the discussion. With regard to the request for precise figures relative to wave-reduction, he might explain that his Paper (prepared about 5 years ago) was not written with the question of wave-reduction primarily in view; otherwise he would have prepared special matter relative to that subject. Mr. Mitchell.

Mr. Mitchell. With regard to the lantern-slides he had shown, the bulk of the records were inaccessible owing to war reasons, and he had had to make the best of the material available. He agreed thoroughly with Sir William Matthews that spending-beaches were the chief method of dealing with the waves that entered a harbour, wave-traps being generally smaller and quite subsidiary things. As Mr. Moncrieff had pointed out, however, there was a very wide difference between the sizes of the harbours at the Tyne and at Whitby. There was a great deal of truth in Thomas Stevenson's remark, recalled by him, that the difficulties in designing a harbour were pretty much in inverse proportion to its size. The ratios quoted between width of entrance and area of enclosed water were interesting and useful, but the shape of the harbour must also be kept in view. The wave-reducing effect produced in a long narrow harbour having its axis parallel to the direction of the travel of the waves might be totally different from that produced in a harbour having the same area but elongated in the transverse direction. The area and shape of the harbour, the extent of the spending-beaches within it, and the contours of the sea-bottom had all to be taken into account in considering the question of width of entrance. Referring to Sir William Matthews's remarks as to the width between the pierheads on the Tyne it might be pointed out that with the great increase in the size of vessels 1,200 feet was not an excessive width, it being only about a third more than the length of one of the giant Atlantic liners. With that increase in the size of vessels there must be a corresponding increase of sea-room, because one of the great risks in entering a harbour was that a strong tidal current running across the harbour-entrance might twist the vessel when her bow was within the shelter of the pierheads while the stern was still exposed to the current.

Mr. Hindmarsh. Mr. R. F. HINDMARSH wished also to express his thanks for the kind reception given to his Paper. Sir Whately Eliot had referred to a 7-foot bar, but the minimum depth on the bar before the Tyne Commissioners commenced their operations was about 6 feet at L.W.O.S.T., while now dredging was from time to time carried out to 30 feet at L.W.O.S.T. Sir Whately Eliot had also mentioned the loss of a sailing ship there with all hands, and there had been other similar instances on the Tyne. He remembered standing on one occasion in the tunnel on the north pier when an enormous wave passed up the entrance-channel, the wave being so high that as it passed the crane on the south pier it completely obscured the top of it. He made some rough calculations afterwards and concluded that that wave must have been over 50 feet in height

crest to trough. On another occasion, in 1908, he was locked up in the south pier lighthouse during a storm for 4 hours, during which he observed the height of the waves at the south pier buoy with a theodolite. The greatest height of wave he measured on that occasion was 28 feet from crest to trough, not from a single wave but from a series of observations; and since then observations on the two pier-end buoys had been taken every day when there was anything to measure. No greater height had been measured since that date. Mr. Gedye had expressed the view that the Tyne was correctly designed in every respect, and Mr. Hindmarsh agreed, except with regard to the bend in the South pier, which was unavoidable because the harbour had to be redesigned when the pier was half built. If he had to redesign that harbour it would be in much the same form, except that he would bring the south pier straight into the beach without the bend, which undoubtedly caused a certain amount of reflection of the waves. He did not consider the entrance, 1,180 feet between pierheads, was a bit too wide. By a rough calculation he estimated that 36,000,000 cubic yards of water came in and out at each spring-tide, and Mr. Messent, before fixing the position of the pierheads, took very careful observations. There was a $2\frac{1}{2}$-knot current at spring-tides, and having regard to the requirements of navigation he thought it would not do to increase that much. There was also the question of possible scouring on the bottom of the sea. If the current were increased much it might do more scouring than was in the interests of the port. The Tyne was largely used as a harbour of refuge by vessels making for adjoining ports, and when approaching from seaward in bad weather the entrance did not look any too wide. He thought it was safe to say that the width of the entrance at the Tyne was about right. It was an interesting fact, as showing the efficiency of the wave-traps, that, when he was measuring the height of 28 feet at the lighthouse, a wreck took place on the Black Middens, while at the same time trawlers were lying at the fish-quays at Tynemouth discharging fish: which showed that the wave-reduction was fairly efficient. In a heavy storm the waves were waves of translation for some distance outside the harbour. He thought Sir William Matthews's measurement of 40 feet was probably correct. The south pier lighthouse top had twice been knocked in by the sea, which showed that undoubtedly there had been heavier seas than when he himself measured the height of the waves. With regard to the rocky foreshore, the Commissioners removed a portion of the Black Middens, and after that there were complaints from the people immediately up the harbour with regard to increased

Mr. Hindmarsh.

Mr. Hindmarsh.

range. He thought those rocks formed a very valuable wave-breaker within the harbour, and he was glad to receive so much support for his view that nothing should be done to interfere with that splendid natural wave-trap on the north side or on the south side. The storm referred to by Mr. Moncrieff as having done damage to Seaham and to Sunderland only did damage at the Tyne to the value of about £5. That again was an illustration of the great value of those natural spending-beaches. With regard to the bend in the south pier, it had been thought from time to time that a spur might be put there, but the Tyne Commissioners had always held very strong views that nothing should be put inside the harbour in the way of spurs, or groynes, or other things which might form an obstruction to navigation; and he thought the wisdom of that view had been borne out time after time. On the 17th January, 1912, with the wind south-east by east and a velocity of 50 miles per hour, a wave 22 feet 6 inches from crest to trough was measured at the pierheads, the period of the wave being 10 seconds, and that wave was reduced at the Tyne Piers shipping staiths on the south side to 25 inches. On the 18th January, 1912, wind south-east, velocity 26 miles per hour, a wave 22 feet high from crest to trough with a period of 11 seconds, was reduced to 26 inches at the south and 27 inches at the Fish Quay on the north side. On the 29th October, 1919, with wind east-north-east, velocity 38 miles per hour, the wave was 23 feet at the pier-ends, its period was 8 seconds, and it was reduced to 26 inches at the south side and 24 inches at the north side. He thought the discussion had tended to prove the statement in his Paper that the only way to reduce waves entering a harbour was to arrange for their lateral expansion, whether by causing the harbour in plan view to widen rapidly immediately within the entrance, or by intercepting, by means of spurs or groynes, the ends of the entering waves, thus admitting of endwise expansion after the interception had taken place; or by the combination of those means.

Mr. Simpson.

Mr. SIMPSON also desired to thank the members for the cordial reception given to the Papers. It had been said that Sunderland Harbour did not face in the direction of the worst storms, but he thought there was a misapprehension with regard to that. The harbour faced the east, and during the war the navigating regulations provided that when vessels approached with an offing of about 3 miles they should come in on a course magnetic west, which took them straight into the harbour. The end of the south protecting pier was tucked in under the head of the north protecting pier, the object of that arrangement being to shelter the end of the south pier from the most violent storms, namely, the north-easterly gales.

Mr. Simpson.

If the south pier had been laid down, as it might have been, so as to form a symmetrical entrance, with the two piers abreast, then, in north-easterly winds, there would be much more disturbance than there was now in the south spending-basin. Therefore the north pier was planned to overlap the south pier and afford it protection by cutting off much of the heavy seas that would otherwise be guided by it into the harbour during north-east storms. The difficulty of beam seas at Sunderland was more fancied than real. The waves when they approached the harbour-mouth began to conform to the general submarine contours, and to bend to the shape of the entrance, so that the question of beam seas was not really a serious one. It had been said that the entrance to Sunderland was too wide. If the piers had been longer he would have made it very much wider, because when one was out at sea watching the waves driving into the harbour-entrance there did not appear to be much sea-room for navigation. He had had the advantage during the war of patrolling off there for 4 years, and had thus had unique opportunities of studying the action of the sea off Sunderland Harbour in all kinds of weather. With regard to the height of waves entering the harbour, the 15 or 16 feet mentioned in the Paper was a fair figure and not an exceptional one; it was the height of the waves during a strong gale, but he himself had been out there in seas which he could only describe as being similar in appearance to those found in the Bay of Biscay. From the waterline of the ship to a man's eye on the bridge was about 14 feet, and on several occasions nothing of the land could be seen, although there was a good deal of high ground in the immediate vicinity. He was quite sure those waves were at least 20 or 22 feet high. A good deal of comment had been passed on the south outlet in making comparisons. The south outlet was no harbour; it had been built merely as a protection to the south docks gateways, and, although the main traffic was formerly carried on through the south outlet, that outlet was always recognized by mariners to be a foul passage, as the sea approach to the channel was studded with reefs. In bad weather the sea ran athwart the entrance, and it was impossible to keep the channel open unless dredging was carried out 500 feet seaward of the pierheads. Even then, two or three winter storms would fill the trench that had been dredged in the summer time, and as much as 6 to 8 feet of water would be lost; consequently the delays to vessels on account of insufficient water were very serious, and led eventually to the construction of the protecting piers at the mouth of the River Wear and the development of the deep-water channel there.

Mr. Simpson. His idea about harbours was simple. A small harbour could never be built to give the results which a big harbour would give, so far as the reduction of wave-action was concerned. He looked upon a harbour, externally, as a machine for wave-reduction, and the question was how best to make it an efficient machine. In a big harbour no spurs, jetties, projections, or traps of any kind should be introduced anywhere near to a navigation channel. The effect of introducing these or other obstructions was to make navigators nervous about taking the harbour in bad weather. If wave-traps were placed too near a channel, the waves were piled up in the traps and recoiled into the channel with a heavy backwash, causing broken water in which a ship would not answer her helm. Therefore in a big harbour there should be a clear course right in from the sea. In navigating into Sunderland, if the weather was north-easterly the master would hug the Roker or north pier; on the other hand, when coming in under a south-east gale he hugged the end of the south pier. In both cases his object was to have as much sea-room as possible in which to recover position if he was pushed out of his course by the waves in passing the entrance. On account of the increasing size of vessels, it was necessary to give the biggest of them an opportunity, if they got out of their course, of righting themselves before they reached the inner door of the port, and that was why the pierheads should be a long way from the inner harbour-entrance. At the south outlet the gateway entrance was protected by wave-screens or jetties, which further reduced the waves passing the pierheads which had not been reduced fully, but large vessels coming in were practically up to the wave-screens shortly after passing the pierheads, and if they happened to miss the narrow opening between them they might carry away one of the jetties and expose the dock-gates to the heavy waves. The alteration of the new south pier, suggested by Mr. Wake, was approved by Sir John Coode. As Sir William Matthews had pointed out, if that pier had been carried out as originally proposed, with the deep water there was at Sunderland there would have been a very strong run of sea along the pier and into the harbour. Wherever an arm was thrown out into the sea, the waves would turn and travel along it.

*** Mr. Sandeman's reply will be found at p. 246.—SEC. INST. C.E.