Discussion.

The PRESIDENT, in moving a vote of thanks to the Authors, observed that the members would appreciate very much the fact that important harbour-works in Australia had been brought to the notice of The Institution in three very interesting communications—Papers which showed that the conditions in Australia were quite different from, he might almost say, anywhere else. The President.

Mr. T. A. COGHLAN, Agent-General for New South Wales, remarked that he was very pleased to have the opportunity of hearing three Papers read on such an important question as the treatment of harbours in Australia. He was hardly in a position to say anything as to the merits of the Papers, and therefore he could not be expected to open a discussion upon them; but he felt that they were meritorious from the point of view of the researches made and the work done by the Authors; and the question whether the ideas propounded in the Papers were good or bad would be discussed by those competent to speak upon such matters. He was very glad to see that the Authors were not unmindful of their obligation to impart to their professional brethren in other parts of the world the results of their investigations and experience in Australia. In doing this they had availed themselves of the opportunities afforded by The Institution, whose work was known wherever civilization extended; and it was a very happy circumstance that engineers in the distant dominions of the Empire were welcomed to lay before The Institution their experience and ideas, and at the same time had the full satisfaction of knowing that they were placing them before a learned and impartial body. He desired to express his appreciation of the kind reception given by the members to the Papers, and he hoped the discussion would be fruitful of ideas and corrective of misapprehensions. Some of the theories put forward —especially those in Mr. Halligan's Paper—were in a sense novel, and he trusted that the discussion would be for the benefit not only of engineers, but also of the various States in whose employment the Authors were, or had been. Mr. Coghlan.

Mr. CECIL W. DARLEY observed that in discussing three Papers at once it was difficult to know where to begin—and perhaps still more difficult to know where to end. In Mr. Halligan's Paper some Mr. Darley.

Mr. Darley. new theories were expounded, and while he was glad to see the Paper brought forward and discussed, he could not quite agree with its author's conclusions. Mr. Halligan attributed the movement of the sand on the coast to the littoral current, and pointed out that, by reducing the velocity of the current at the entrance to less than that of the littoral current, the inroad of sand could be stopped. Mr. Darley differed from him on that point. Mr. Halligan instanced Sydney Harbour, Jervis Bay, and Botany Bay, as cases of wide entrances, but it happened that those three entrances had no adjoining sandy beaches; they were entrances through rocky headlands and could not be compared at all with the rivers cited in the Paper. Sydney Harbour had a rocky headland north and south for some distance, and there was no sand-movement there. Thirty-five years' experience on that coast, in close study of the harbour question, had led him to the conclusion there was no travel of sand on the coast due to the littoral current. The movement of sand was local, and due to various local causes, in each case. In some cases there was no doubt that the seas brought in the sand; there was a sandy bottom outside, and the sand was brought into the harbour at right angles and thrown up on the coast; it was not by any means travelling from the north or from the south. Mr. Halligan endeavoured to prove that most of the travel was from north to south. At the Manning River and the Richmond River, the sand-spit encroached on the entrance from the south. On his first visit to the Richmond River, more than 40 years ago, the entrance to the river was nearly 1 mile south of where it was shown on the chart to-day. At that time he saw an incoming steamer struggling to turn at right angles on the bar in order to pass into the river; more recently the entrance had been close up under the north head. The word "Lagoon" on Fig. 7, Plate 5, marked the position of the channel which was seen by Sir John Coode when he visited the harbour. In other words, the entrance had moved more than a mile from the north head to the south. The sand, if it had travelled at all, had come up from the south; it had certainly not come down with the littoral current from the north as the Paper rather would indicate. In all cases on the coast the ebb-current tried to cling to the headland; if the headland was on the south, it would cling to the south; and if on the north, the channel tried to cling to the north. The channel ran up until it met the head at the north of Richmond, and then passed round; but Sir John Coode very properly considered that the channel could not be maintained there, and that there must be a straight run for the river, as straight as possible to the entrance.

The works designed by Sir John Coode, so far as completed, had been successful in fixing the entrance, and very fine navigation had been secured, but in the absence of any river-floods for many years some sandbanks had accumulated within the entrance. In this case the sand was partly brought in by the flood-tide, which passed in along the south beach and round the end of the breakwater, and partly, no doubt, it was blown in from the beach over the breakwater. The wind was a fruitful source of sand-trouble at all the river-entrances. Much the same thing occurred in connection with the Manning River. The lagoon shown in Fig. 6, Plate 5, was part of the old entrance, and the sand, in his opinion, was largely brought in at right angles from the sea and distributed along the coast. The Paper properly pointed out that the tidal wave approached the coast at right angles, but in the case of Newcastle it could not be said to do that, as Newcastle entrance was in a deep bight, the coast on the north trending for about 20 miles in a north-easterly direction. The flood-tide made in along this beach, bringing sand in round the breakwater; thus it was the flood-current that brought the sand in, not the littoral current. The sand at the entrance was fed entirely from the north beach. Mr. Darley.

With regard to the second Paper, the north breakwater was designed by Mr. Darley's predecessor, the late Mr. E. O. Moriarty, who was Engineer-in-Chief in those days, and he himself was there as resident engineer. In making the breakwater the stone had to be landed in punts and run out across the sand-spit at Stockton. At that time the north spit, which was covered with grass, projected towards the channel about 520 feet southward of the line of wall leading to the breakwater; but as soon as the breakwater was advanced beyond the line of sandy beach—thus cutting off, for a time, the inrun of sand—the spit rapidly disappeared under the influence of the ebb-tide, until the wall leading to the breakwater became the water's edge. Gradually, as the breakwater went out, the beach grew out with it, and the sand coming in from the north filled in the bight, following the breakwater, and eventually commenced pouring round the breakwater again with the flood-tide. Before completing the north breakwater, the south breakwater was extended out to sea: it was found that it would not be safe to go farther out without the shelter of the south breakwater, as it was catching the seas and disturbing the shipping in the harbour too much. He designed the outer north breakwater to start farther north and leave a space between as a wave-trap; and so far it had acted efficiently. On the south side a training-wall was run out in order to lift the current up to the north side, and a wave-trap was also

Mr. Darley. made there with a view to protect the harbour. It was clear that the sand had not come in with the littoral current. With regard to making the harbour wider, as Mr. Halligan suggested, it was rather wider now than the current could maintain, and putting the breakwaters farther apart would simply mean having more sand between them. A novel piece of engineering was carried out a few years ago by sinking a series of hulls to form a breakwater, but he was afraid he could not recommend young engineers to try that expedient. In his view it did not hasten the construction in this case by a single day. When large vessels were sunk and reached the bottom, their backs broke and all the sand ran out, and the hulls of the broken ships naturally scattered the stones. In his opinion it was rather a curious expedient, and he did not think it even cheapened the construction. The hulls were now all covered in by the breakwater. He did not agree at all with the view that the sand was brought in by the restricted entrance. On the coast south of Newcastle, under certain conditions, with a gale straight in from the east, he had seen the rocky shore turned into a sandy beach by one gale, the sand being brought at right angles on to the coast. It disappeared again very soon, but the fact showed that the sand was brought in by the sea at right angles and had nothing to do with the littoral current.

Fremantle Harbour was another case of a theory set up in the old days with regard to sand-travel. As the Paper pointed out, Sir John Coode accepted the theory that there was movement of sand along the coast, but of course he was not there long enough to make a study of the subject, and had to accept the views of those in authority at the time. He believed the question of sand-travel and the trouble it caused was first raised by the late Mr. Wardell, who at that time was Director-General of Public Works in Victoria, and who was sent round to report upon it. Mr. O'Connor made a close study of the matter, and knowing that so many engineers before him had accepted the theory of sand-travel, he was very slow and cautious in acting against that theory. Having collected all the evidence that he could get, Mr. O'Connor rightly came to the conclusion that there was nothing to be feared from the sand-travel. Sir John Coode's design was for an open breakwater connecting the mainland with the island harbour, intended to let the sand travel between the harbour and the mainland. As there was no sand-travel to speak of—no permanent sand-travel from the north to south, but only local movement of the sand by the various seas—it had been possible to carry out the works described in the Paper.

Sir Whately Eliot.

Sir WHATELY ELIOT wished to confine his remarks chiefly to Fremantle harbour. The Paper dealing with the Fremantle harbour-works was a very interesting one, as it was a record of the successful completion of work which for years had been described and considered to be almost, if not quite, impossible. In 1874, on his way to New Zealand, he stopped at Albany, and with the natural curiosity of youth began asking questions about the harbour; and the people of Albany informed him that it was the only harbour that would ever be made in Western Australia. The mail-steamers at that time called at Albany only. He was also informed by the Albany people that such a thing as a harbour at Fremantle was quite impossible, and that the Government were about to commence the construction of a railway to connect Perth with Albany, which was to be the port for Perth. Now things were rather different. The railway, 250 miles in length, had been constructed, and so had Fremantle Harbour, and instead of the Perth people going to Albany to embark in the mail-steamers the Albany people travelled to Perth to embark. In the Paper reference was made to Sir John Coode's scheme for a harbour at Fremantle, and that scheme was compared in one respect with a scheme by the same engineer for a harbour at Timaru in New Zealand. The reader might be led to suppose there was some striking similarity in the circumstances of those two places; but that was not the case; the only similarity was in the schemes that were drawn up, the local circumstances being totally different. At Timaru there was a long length of shingle beach, with no sand above low-water mark, and the shingle was constantly moving in one direction. The beach travelled in a continuous line along the coast for about 100 miles, and it was quite evident that it came down by the rivers on to the shore and went to the Banks Peninsula. There was no indentation of the coast, no estuary or river-mouth, but simply the travel of the beach. At Fremantle, on the other hand, there was no shingle but only sand, and there was considerable doubt as to the extent and direction of its movement. In addition to that, there was at Fremantle a large lagoon which offered the tempting prospect of being able to open up a harbour without having to build one entirely outside. In 1908 he had an opportunity of inspecting the Fremantle harbour thoroughly, and he was much struck with the construction of the north mole. He had seen something of rubble breakwaters before, and he naturally asked whether that breakwater had to withstand a very heavy sea. He was assured that it had not, and he did not see how otherwise it could have remained where it was, because, although it was protected on the sea side with very large pieces of granite, Sir Whately Eliot. he concluded, from what he had seen of the effect of seas on rubble mounds in other places, that it could not withstand a very heavy sea-stroke. He was also informed then that there had been practically no silting in the harbour since the breakwater was made and the harbour deepened. He also visited the little harbour of Bunbury, where there was an extensive rubble breakwater similar to the north mole at Fremantle: that breakwater also had evidently not a very heavy wave-stroke, being sheltered considerably by the bold Cape Naturaliste to the south. At Bunbury there was a small estuary, and he was told that the effect of the breakwater was to divert the current coming down in flood-time through that estuary. Before the breakwater was built, the sand used to be deposited just inside the area which was now enclosed; but, since the breakwater had been constructed and carried out to its full length, the current from the estuary seemed to be diverted away from the harbour, and there had been no injurious effect from silting inside. Of course, during the construction of the breakwater the sand—as always happened where it was moving about—followed the breakwater, and a small bank was left behind just inside the end of the breakwater. Mr. Palmer said that it was hoped Nature would remove that small bank afterwards. From experience of the way in which Nature dealt with small troublesome banks, however, it had not been thought advisable to give her an opportunity of doing the work, and the bank had been dredged away.

Mr. Griffith. Mr. J. P. Griffith remarked that those who were engaged in harbour-engineering knew well the immense difficulty of laying down any hard and fast rules in connection with the subject, and that fact had been peculiarly impressed upon him during a life spent in connection with the harbour-works at Dublin. As many members were aware, Dublin harbour was a classical example of the struggle against encroachments of sand at the entrance to a harbour. He remembered very well discussing, as a young man, several of these problems with the late Sir John Coode, Past-President Inst. C.E., whose acquaintance he made in the Port of Dublin when Sir John was advising the Board of Trade as to the repairs to the base of Poolbeg lighthouse. What impressed him most was the earnest way in which Sir John Coode sought for information on which to base his opinions. Perhaps the chief lesson he had learned from reading the Papers was the importance of the early investigations, on the results of which engineers had to design works involving so much uncertainty as great harbour-works. He had read with particular interest Mr. Palmer's remarks as to Sir John Coode's visit to Australia on behalf of the Government, and his recommendations in connection with Fremantle. It appeared that it was afterwards discovered that some of the information laid before Sir John Coode was not correct, and subsequent engineers had had to modify the works accordingly. He simply referred to that matter in order to emphasize the importance of the preliminary work of investigation. In turning to the consideration of the Australian problem one was met at once with the urgent necessity for the works, and the comparative absence of knowledge, before their construction, on the subject of the ocean-currents and littoral currents, as well as of the tidal forces that had to be dealt with. All forbearance should therefore be exercised in criticizing the important works described in the Papers. He thought The Institution was greatly indebted to its members and others scattered abroad for furnishing such information. Nothing was more valuable to the profession than to have these descriptive Papers printed in the Proceedings, for reference in years to come by engineers engaged in similar work. He had discovered during his life that nothing was of greater value than the historical aspect of a port. If Dublin had not had the magnificent surveys made in the year 1820 by the late Mr. Francis Giles, the father of a Past-President of The Institution, he could hardly imagine that the entrance to Dublin harbour would be what it was to-day. About the year 1820 the Government engaged the elder Rennie to advise as to the possibilities of Dublin harbour. He reported that no greater depth could be hoped for on the bar of Dublin than about 8 feet at low water, and he gave up the idea of improving the entrance across the bar, and suggested a ship-canal from a point along the coast adjoining the site of the present Kingstown harbour. Fortunately for Dublin, the harbour-authorities were so impressed with the possibilities of improving the bar that they got Mr. Francis Giles to make a survey of the bay. It was this survey that really determined the future engineering policy of the port, as by means of it the littoral currents, which were the dominating feature controlling the entrance of Dublin port, were discovered. But for this survey, the works carried out by the elder Halpin in conjunction with Mr. Giles could never have been properly designed and executed. The result of these works was that, instead of having 6 feet of water on the bar as in 1820, the construction of the piers alone, without dredging, increased the depth on the bar to 16 feet at low water. That, he thought, was a striking example of the importance of early investigations in connection with harbour-works. He did not propose to criticize in any way the works carried out at Fremantle or at Newcastle; they had been carefully thought out and systematically executed, and had considerably improved Mr. Griffith.

Mr. Griffith. those ports. It should not be forgotten, however, that a great many of the improvements were due to the mechanical appliances which were now at the disposal of engineers. The suction dredger had come to the rescue in places where the bucket dredger was unavailable. The only danger in the future was that engineers might lean too much upon the mechanical side, and on the power of dredging. It was possible to do anything with plenty of money and dredgers, and under those circumstances a port could be maintained even in the face of exceptional difficulties; but he thought that in the first instance engineers should study the physical features they had to deal with, and utilize the forces of Nature as far as possible, supplementing them, if necessary, with the mechanical appliances now available. With regard to Dublin, through the great works constructed in the early part of the nineteenth century, about 10 feet had been gained in depth over the bar. About the year 1880 the bar seemed to come to a standstill, and it fell to his lot to advise as to what could be done. There were various proposals for narrowing the entrance and increasing the scour, and also for increasing the tidal volume thrown on the bar; but with the knowledge already gained he thought himself justified in recommending the Port Board to cut through the bar so as to have 20 feet at low water, and he believed there was sufficient scouring-power behind to maintain the deepened channel. He was glad to say that, as far as the work had gone, his forecast had been fulfilled. The channel had been deepened to 20 feet at low water by dredging, and since dredging was stopped there had been a further increase in depth, due evidently to the scouring-power that produced the first improvement. He could not help thinking that those were lines of procedure which should be kept in view in connection with all such works. Mr. Halligan's Paper was a thoughtful and speculative one, which required very careful consideration. It fell foul of many established ideas of one who, like himself, had been brought up in harbour work, and the only way in which he could approach it was by asking whether the propositions advanced in the Paper applied to the port in which he was particularly interested. Mr. Halligan insisted that the ocean-current was the only sand-transporting influence to be dealt with. That was not true with regard to the Port of Dublin. It might be perfectly true in New South Wales, or on the Australian coast generally, but it did not apply to Dublin Bay. There the encroachment of the sand was unquestionably due to wave-action; the flow of the sand was in the direction of the maximum wave-stroke and of the most injurious wave-action. The tidal currents, ebbing and flowing up and down the channel, produced extremely little effect in the transportation of sand along the Irish coast, and all the information at his disposal pointed to the travel of the sand being due to wave-action. He could not help thinking that if Mr. Halligan followed up his investigations he would find that the waves, which were a very important factor according to his own showing along the coast of Australia, were a potent force in connection with the question of sand-movement. When waves rolled over a sandy bottom—he had almost been about to say, no matter at what depth—the pressure of the wave was transmitted to the bottom, and acted more or less as a roller, producing a movement of the sand. His own experience was that even around the deep-water portions of the coast in the Irish Channel there was sand-travel, which he was confident was not due to the main tidal current running up and down the channel. If it were, there would be complete confusion with regard to sand-travel, as there were so many eddy-currents produced by the promontories along the coast. Mr. Halligan also referred to the importance of the width of an entrance being so arranged that the current in and out of the harbour should not be faster than the tidal current, or, in his case, than the ocean-current. That also was contrary to what was met with in Dublin. The great object of the piers of Dublin Harbour —one of which was $3\frac{1}{4}$ miles long, and the other $1\frac{3}{4}$ mile—was to concentrate the last half of the ebb on the bar, which was 1 mile outside the piers. The whole problem of the improvement of the bar channel had depended on the concentration of that ebb from the harbour, at a higher velocity than the adjoining current. At Dublin the ebb-tide was the dominating tide, being faster than the flood-tide, and it was possible to concentrate the ebb on the bar by means of the currents in the bay beyond the piers. The levels of the tidal water north and south of the bar, as it were, bounded the outflow current. He only mentioned that as a reason why he could not accept as a general conclusion Mr. Halligan's reference to the width of entrance as being a dominating factor. He was afraid he had rather unduly dwelt on his own port, but it had been the guiding feature in his mind when reading the Papers. He thought The Institution was greatly indebted to all the Authors, and especially to Mr. Halligan for the fearlessness with which he had dealt with the subject, knowing that his views were not quite in consonance with the views of engineers connected with harbours in this country. Mr. Griffith.

Mr. A. F. Fowler considered that great importance must be attached to Mr. Halligan's observation that every case of improvement of a river or estuary had to be studied by itself, and any remark Mr. Fowler.

Mr. Fowler. which he himself should make was subject to that postulate. He thought Mr. Halligan was perhaps rather sweeping in saying that too little improvement had been effected for the large amount of money expended. Mr. Fowler must not be taken as detracting from the merit of the work performed by all the engineers who had been connected with the Newcastle entrance, when he said that he was somewhat envious of the almost perfect conditions for improvement that existed in that case. He alluded to the large drainage-area behind, as compared with most English rivers, the comparatively small range of the tide and its low velocity, the bottle-necked formation at the entrance, and the almost entire absence of suspended matter in the water. According to Mr. King, the suspended matter took 1 to 3 days to settle in a tumbler. That was in marked contrast with what obtained in the Humber, where, when he was stationed at Goole under Mr. W. H. Bartholomew, M. Inst. C.E., he frequently noticed, at the confluence of the Humber, the Ouse, and the Trent, between 2 inches and $2\frac{1}{2}$ inches of sediment per tide. In the estuary with which he had been intimately connected for the past 20 years, the Ribble, the amount of suspended matter rolled up by the flood-tide in its earlier stages was 1,120 grains per gallon. One point in Mr. Halligan's Paper was of intense interest to him, namely, the allusion to the fetish of the scouring-power of the ebb-tide. That was a question which, more than any other, had to be considered with regard to the circumstances of a particular case. He might be excused for pointing out that in many estuaries an ebb-tide was only flood-tide water going back again. In order to get increased scouring-power from the ebb-tide, it had to be contracted by means of works of some considerable magnitude, depending upon the range of the tide. Taking the case of the Ribble, where there was a maximum range of tide of 30 feet, the greatest velocity on the ebb-tide was during a short period of half ebb, or a little after, while the greatest velocity on the flood-tide was on the first hour of the flood. It was astonishing, in the case of the Ribble, that throughout the improvement of the Ribble estuary the mental problem had constantly been, how to get from Preston to the sea, ever bearing in mind—almost to the point of obsession—the scouring effect of the ebb-tide. He ventured to think that if the problem had been looked at from the point of view of how to get the sea to Preston, different methods might possibly have been adopted. In order to get increased scour on the ebb-tide it was obviously necessary to contract, and to get the most effectual scour it was necessary to contract up to the height when the velocity of the ebb-tide was at its maximum. In the case of the Ribble that meant that the upper 4 miles had to be treated by raising Mr. Fowler. training-walls to 20 feet above sea low-water level. Of course it was easy to speak after the event, and he realized now that the works put down to train the ebb so as to make the most of the scour had been of such magnitude that they had reduced the quantity of flood-water, and therefore much scouring-power had been lost upon which dependence had been placed for improvement. The result on the Ribble had been that, whereas in 1850 the sea low-water line approached to within 9 miles of Preston Dock, at the present day it was 2 to 2½ miles lower down. Therefore the natural gradient was decreased from what would be due to any given fall in 9 miles to the same fall in 11½ miles. The estuary above that point, and up to where the river contracted and lost its estuarial nature, had accreted no less than 4½ feet over the whole of the southern portion, and about 7 feet on the northern portion, the latter bearing only the ratio of about 1 to 5 to the southern portion. The result was that 29 million cubic yards of tidal water had been abstracted from the estuary, that was, 29 million cubic yards less of water were ebbing out. It seemed to him, therefore, that in treating estuaries like the Ribble, the Mersey, the Dee, or the Seine, it was a matter for serious consideration whether the idea of training-walls for contraction with a view to encourage the ebb scour should not be dropped, and the fullest use be made of the forces of Nature, as advocated by Mr. Griffith, doing nothing which would go against Nature. When a training-wall was constructed and the flood-tide was found to be attempting to break from the back of the training-wall into the channel, it was obvious that there was something wrong in the position of the wall. Therefore he thought a comparison of the two systems of training and revetting—that was, merely protecting the edges of the channel which Nature formed, so as to prevent it from moving, the principle which was now being adopted by Mr. Lyster on the estuary of the Mersey—was worthy of consideration. During his official connection with the Ribble he adopted the system of putting in low revetting, with a considerable degree of success. Lately the old idea promulgated by the Ribble Commissioners had been reverted to on the Mersey, and a channel had been formed through the sandbank. It was too early yet to express any opinion as to what the result would be, but it would be a very interesting case to watch. On the Mersey the bar was being dredged to admit the flood-tide freely, and the natural channel, the Queen's Channel, was being revetted at Taylor's Bank to keep it in position; and that could be compared with the

Mr. Fowler. Ribble estuary, where double training-walls were leading the ebb-tide through a sandbank straight out to sea. With regard to Fremantle, the question of the travel of sand by littoral drift had been fully discussed by The Institution in 1896 upon a very interesting Paper by Mr. W. H. Wheeler. It would appear that in the case of Fremantle there had been great difficulty in ascertaining the direction of the littoral drift, and the experience gained there would indicate that in cases where it was difficult to determine whether the drift was from north, south, east, or west, it might safely be ignored, as indeed it was at Fremantle. In only two instances had he had occasion to deal with a littoral drift; one was on the Ribble and the other at two places on the Cumberland coast, namely, a small harbour at Harrington and at Workington. In these two places the littoral drift was obvious. There were blast-furnaces on the south side of the entrance to each of these harbours, and both entrances were threatened by the constant travel of slag to the north-west. In the case of Harrington the breakwater had had to be extended about 200 feet seaward, and at Workington a similar extension had been recommended by him, but so far it had not been carried out. The quantity of slag moving along the foreshore was immense, and the travel was particularly striking because, although in each case there were ironworks to the north of the harbour, the north shore was absolutely clear of slag. He had drawn attention to those two cases merely to show that in both the littoral drift was in the direction of the prevailing wind and with the flood-tide. In that respect he thought they bore out Mr. Wheeler's statement and also what Mr. Griffith had said, as to the direction of the strongest wave-action. In the case of the Ribble there was a bank of stone which was driven into the estuary on the north side. The gravel took the line of least resistance, and the angle of incidence of the flood-tide with the foreshore and prevailing wind drove it up into the Ribble. Reverting to the ebb-tide, his experience had led him to resolve never to consider one phase of the tide to the almost total exclusion of the other phase, and he thought Mr. Halligan had done a great service in drawing attention to the fetish of the ebb-tide scour. It was not always a fetish, but sometimes it was a will-o'-the-wisp which led engineers into difficulties from which it was very hard to emerge.

Mr. Davis. Mr. Joseph Davis remarked that he had the advantage of knowing a little of the circumstances connected with the works referred to in the Papers, and he could say that Mr. Halligan's observations in regard to the New South Wales rivers might be absolutely relied upon. But the conclusions drawn from those observations were open to criticism, because many of them were scarcely in conformity Mr. Davis. with the facts. All credit was due to Mr. Halligan for presenting the results of his work and for raising important and difficult questions, even though the views he expressed did not in the main agree with those generally accepted. When the special conditions of the Australian rivers were known, it would be seen how difficult it was to arrive at conclusions, and how doubtful the results of harbour-works would be. Mr. Halligan's remarks as to the effect of the flood-tide appeared to be scarcely in accordance with the circumstances; the facts were, to Mr. Davis's knowledge, as Mr. Darley had stated them, and as had been stated by Mr. Griffith in regard to Dublin. Sand from the ocean was thrown up—possibly to some extent by a littoral current, but principally by the action of the waves, especially during a gale—on to the bar at the entrance to an estuary, and so far as he had been able to gather, none of the sand thus thrown up was carried into the entrance. Silt or sand, or the fine material brought down from the uplands, was carried out to sea in all but very exceptional cases, and any sand found—for instance in the case of the Richmond River entrance—was not derived from the ocean, but was either the result of the works themselves, or was due to drift. Looking at the map of the Richmond River entrance (Fig. 7, Plate 5), it would be seen that there was a spit of sand immediately over the word "South" on the south side of the entrance, and that sand, to his own knowledge, was the result of drift. There was a very long length of exposed sand to the south, and when the wind blew fiercely it carried the sand over the southern breakwater into the channel, and was really the cause of the sand-spit. It would be seen that the channel followed the north training-wall, then shot across to the concave part of the south breakwater and then went out to sea; but, so far as he was aware, the bar itself generally formed, according to the state of the weather, some distance outside the entrance: which showed pretty conclusively that any sand thrown up by the sea remained there until it was removed by the dredger. Another thing that proved to him that that was the case was the great demand there always was for suction dredgers immediately after a gale, owing to the quantity of sand thrown up by wave-action. With regard to the effect of the ebb-tide, Mr. King's Paper showed fairly conclusively that the effect of the works carried out at Newcastle had been to move the sand seaward by means of it. There was a definite statement in the Paper that the effect of the ebb was to carry the sand out to sea in the immediate vicinity of the north and south breakwaters, and he was able to confirm that from personal knowledge of the works. With reference to the sinking

Mr. Davis. of the hulks, Mr. Darley would pardon him for differing from the conclusion he had arrived at as to that method of constructing breakwaters. Mr. Davis happened to have been one of the Board who advised that that mode of procedure should be adopted. Mr. Darley would remember that he prepared an estimate for the northern wall and allowed for its construction to a certain depth; but during the construction of the work, after Mr. Darley had left the colony, it was found that the flood-tide and ebb-tide scoured away sand to about 30 to 36 feet below the level at which Mr. Darley expected his wall to be. The result of that was to increase considerably the cost of the wall, as it had to be constructed to a further depth of 30 to 36 feet, and it became a question whether an expenditure two or two-and-a-half times what had been expected was to be incurred. It was then suggested by one of the members of the Board that hulks should be sunk, and the suggestion was thought worthy of being acted upon. It was recognized that when the hulks took their bearings they might possibly break up, but it was thought they might stop the scour that was taking place at the end of the wall; and in the result that expectation was realized. The scour was arrested immediately, and the wall was carried forward rapidly. Possibly some scouring took place on the inner side of the hulks, and the wall on that side would be much deeper than on the outer or sea side. Mr. King described on p. 155 the beneficial immediate and ultimate effects of the sinking of the hulks and punts; and possibly Mr. Darley, when he made his remarks, was not fully aware of the circumstances under which the hulks were sunk, or of the result of their sinking. Mr. Davis had been associated with the harbour-works of New South Wales for some time, but Mr. Darley had been connected with them practically from their infancy up to a year or two ago, and therefore he could speak with most authority. Nevertheless, as far as Mr. Davis's own observations went, he would say that the proposals made by Sir John Coode, modified by Mr. Darley, and carried into effect with such slight alterations as were found desirable from time to time, fully justified the opinion formed by Sir John Coode and the advice he gave. He thought Mr. Halligan was entirely wrong in his idea of leaving the entrance as wide as possible. He could confirm Mr. Darley's statement that in the vicinity of the wide entrances cited there was no sand to cause trouble. The diagram of the Manning River entrance demonstrated fully the peculiar conditions of Australian rivers. The entrances of the rivers often shifted about for long distances, and before the channels were fixed by training-walls the rivers might break through at any point along the sandy strips which were features of the entrances to rivers in New South Wales. He thought it was highly probable that the sand-spit marked at the Manning River entrance (Fig. 6, Plate 5) between the ocean and the channel itself, immediately above the words "Ballast Wall," had been a moving spit from time immemorial. Respecting the Fremantle harbour-works, he wished to bear his testimony to the good work that had been done. So far as it had gone, the work might be regarded as an artificial basin with an entrance approximately on the site of the Swan River. The Swan River was a very small one. It had simply had to be deepened and the basin made. The work had been costly, and to extend the harbour would cost much more. Two bridges—a railway-bridge and a road-bridge—would have to be removed before any extension could take place. The good work that had been done at Fremantle bore abundant testimony to the sound judgment of the late Mr. O'Connor. Mr. Davis.

Mr. C. S. MEIK remarked that the Papers of Messrs. King and Palmer did not lend themselves much to criticism by those who had not an intimate knowledge of the coasts of Australia, but the Paper by Mr. Halligan was one that was open to very serious criticism by all engineers. It appeared to him that the author of this Paper had started to write with a preconceived idea, and that he had followed that idea all through the Paper. For instance, on p. 136 he said that the point he wished to make was that it was the current and the current only which caused lateral movement of the sand on the littoral. Mr. Halligan had apparently started off with that erroneous assumption—"erroneous" in the sense that it was contrary to the opinions held by engineers accustomed to sea-works—and he followed that assumption throughout and made his facts, and one might almost say his currents, fit in with his theory. For instance, in *Figs.* 2 (p. 130) he gave an illustration of a main current setting southward coming against a promontory, being reversed, and travelling northward; that was to say, the current inside was travelling to the north, while the main current on the outside was travelling to the south, the idea being that the current had necessarily to travel north in order to carry the shingle and sand northward and deposit it where it had been deposited at the river-mouth. Of course the most obvious question that would occur to a reader would be: "What becomes of that northward current?" If it travelled north it must go somewhere. It must either pass under the southward current or enter a river-mouth where it lost itself—which was absurd. Mr. Halligan started by saying that each locality Mr. Meik.

Mr. Meik. must be judged on its own merits: that was quite true, and was exemplified by the case in question. What had really happened was obvious. The sand had been carried northward by the action of the sea due to the prevailing wind in the locality, and the sand had been deposited in the northern part of the bight: in order to account for its being there, Mr. Halligan reversed the current. That led to the main point as to what was the cause of the drift along the shore. As Mr. Griffith and Mr. Fowler had pointed out, there could be no question whatever that the cause of the drift was the action of the waves. It happened sometimes that the action of the current was coincident with it, but, to his mind, there was no question that it was wave-action that caused the sand and shingle to travel along the coast. The motion might be accelerated or retarded by currents, but the fact remained that its chief cause was wave-action. On p. 137 Mr. Halligan said: "Standing on one of these headlands on a bright day, one may often see sand close to the rocks, held in suspension by the water." That, Mr. Meik thought, meant that the contention of the Paper was that the current carried the sand in suspension, which of course with a 2-knot current was out of the question. A 2-knot current might carry silt, or very light material like silt, as could be seen in the Thames, but not sand, and certainly not quartzite sand such as was described by Mr. Halligan. It was true that the littoral currents could cause sand to move, but that sand had first of all to be stirred up by wave-action. The littoral current was not strong enough to raise sand off a beach and carry it along the coast. Mr. Halligan also expressed some extraordinary opinions about harbour-entrances and the scour of the ebb-tide, but that matter had already been dealt with, and Mr. Meik would not labour it. Coming to the question of the width of harbour-entrances, Mr. Halligan had apparently overlooked the fact that harbours were constructed mainly to let ships in and keep the sea out. It stood to reason that, unless the width of the harbour-entrance was restricted, it was impossible to keep the sea out, and therefore the utility of the harbour for vessels was very much diminished. In the conclusions on p. 148, three controlling influences were laid down, and the statements were made that if they were observed they would be sufficient for the designing of any harbour on the coast, and that the problem thus became much simpler than on some other coasts where such favourable conditions did not exist. Mr. Halligan took no notice whatever of the sea, though the sea presumably was a factor to be dealt with on the coast of New South Wales, just as it was on the coast of Great Britain. Therefore Mr.

Meik thought Mr. Halligan's conditions were, to say the least, very incomplete. Presumably Mr. Halligan was not an engineer, otherwise he would not have been so rash as to bring such heterodox opinions before The Institution. Like a great many nautical men, he based his conclusions more on what was observed from the deck of a ship than on what had been actually found by carefully surveying the harbours or coasts of a country—an examination civil engineers always had to make when engaged in harbour work. Mr. Meik.

Dr. J. S. Owens observed that on p. 130 there were a few diagrams illustrating the effect of headlands upon currents, and the first diagram showed a current reversed. He knew of several instances in this country where there were such currents, and the reversed current did go somewhere. Where it went to was, he thought, clear enough: it came back again on the outside. As a matter of fact, some embayed parts of the water behaved somewhat like a pulley with a belt going over it, simply revolving as an eddy. He could call to mind several cases where the drift was determined by the direction of that eddy-current. What he wished chiefly to speak about was the movement of material due to waves and currents, because it appeared to him that the distinction between the behaviour of shingle and of sand had not been drawn by Mr. Halligan or by any of the speakers. His own experience had been chiefly in connection with sea-defence works, and he had found that sand could be moved by a moderately slow current, while shingle could not be moved by so slow a current. He did not know the coast referred to in Mr. Halligan's Paper, but he gathered that shingle was not very plentiful there, and that the conclusions were drawn from observations of the behaviour of sand. He had investigated the movement of sand and shingle, and had determined the actual velocities required for it; and he had discovered a point which he would not go so far as to say explained the behaviour of wide-mouthed harbours, but which certainly struck him as being very peculiar and as having a bearing upon the movement of sand. The ordinary sea-shore sand, composed of quartzite grains perhaps $\frac{1}{50}$ to $\frac{1}{100}$ inch or a little more in diameter, would begin to move along the bottom when the current attained a velocity of about 0·85 foot per second, and it would continue moving for all velocities above that; but the curious point was that there were two distinct stages in the movement of the sand. From 0·85 foot per second up to 2·5 feet per second the sand moved in the form of ripples. Everyone knew the ordinary sea-sand ripple, with a flat slope facing the current and a steep slope away from the current. Between 0·85 foot and 2·5 feet per second, the sand Dr. Owens.

Dr. Owens. moved by being rolled up the flat slope and dropped over the steep crest; it became buried in the trough, and did not stir again until the whole ripple had moved over it. Under those circumstances it moved slowly; in fact, the quantity of sand moved by such a current was trivial. But, immediately the velocity exceeded 2·5 feet per second, the whole behaviour of the sand changed. The ripples were swept away suddenly at that critical velocity, and the sand was raised in suspension—not very high in the water, perhaps an inch or two above the bottom—and was carried away extremely rapidly in a smooth sheet, rushing over the bottom with almost the same velocity as the current. Since the bottom was corrugated by the ripples up to that velocity, shingle was unable to move until the ripples were swept away. The effect was that, although a current of 2·5 feet per second (which he made out to be approximately 1·48 knot per hour) could move a stone between 2 and 3 inches in diameter over a hard bottom, it was unable to move it at all over a rippled bottom, and so the shingle had to stay there until the ripples were swept away. Remembering that 1·48 knot was the critical velocity at which sand ceased to move in ripples and began to move in suspension, it was curious that, in every case which Mr. Halligan had brought forward of a wide-mouthed harbour through which sand was not swept, it would be found that the velocity into the harbour fell below that critical velocity. In Sydney Harbour it was 1 knot, whereas the current flowing outside exceeded the critical velocity. In Botany Bay it was $1\frac{1}{4}$ knot in the harbour—still below the critical figure—and outside it was $1\frac{1}{2}$ knot —exceeding it. The velocity of the tidal current into Jervis Bay was $\frac{1}{2}$ knot, and that of the ocean-current flowing by was $1\frac{1}{2}$ to $1\frac{3}{4}$ knot. That was a remarkable coincidence. He was speaking of currents alone, leaving for the moment the question of the waves. It would almost seem that the explanation that a current must fall below the critical velocity in order to prevent the movement of sand would fit these cases better than the view put forward by Mr. Halligan. He certainly could not see any reason why the relative velocities of the current into the harbour and the current flowing by should affect the amount carried in, with the exception of what was probably a trivial factor due to centrifugal action throwing the grains outward at the bend of the current. A sufficient distinction, it appeared to him, had not been drawn between the behaviour of shingle and the behaviour of sand. In England there was plenty of shingle with the sand, and he knew as a fact that the direction of shingle-drift was determined by the direction of the wave-stroke. As soon as waves came on to the shore obliquely, the shingle began to move in the direction in which it was driven by the waves. But that was not so with sand. Sand went where the current went, and provided it was raised into suspension it would go with any current. When sand had been raised into suspension in water, a hydrometer placed in the water would show a higher specific gravity than if there were no sand in suspension. He had obtained hydrometer readings up to 1·4 by simply shaking sand up in water. Now, the erosive power of a current depended profoundly upon the density of the fluid, and the density of the fluid was increased immediately the sand was raised into suspension. Consequently, it seemed to him that immediately sand was raised into suspension, from whatever cause, the current thereby acquired a much more powerful erosive action. Dr. Owens.

Mr. A. E. Carey observed that the points upon which he had intended to make a few remarks had been dealt with so exhaustively by previous speakers that he would confine himself within very small limits. As he understood Mr. Halligan's Paper, what its author said was that the great monsoonal current flowing down from the north-west was in conflict with the local tidal currents, and that this condition of things was the cardinal factor in the regime of that particular coast. Assuming that that was correct, as doubtless it was, it would produce a state of affairs which might be compared with the condition of an inland sea or lake. Practically, the normal condition of a coast-line did not appear to be existent at the part of the Australian coast within the scope of Mr. Halligan's Paper. At La Guaira harbour in Venezuela, which Mr. Carey carried out some years ago, a breakwater was run out into about 45 feet of water. There was practically no rise of the tide at all, the maximum range being about 15 inches. Yet on that coast-line there was a very considerable sand-travel. The great feature in the Caribbean Sea was the prevalence of the north-east trade-winds, which blew for 9 or 10 months in the year, stirring up the sandbanks along the coast-line and driving the sand along the shore. The wind waves carried the sand round the breakwater, when constructed, and deposited it to a large extent in the harbour, with the result that steady dredging was necessary to remove it. Mr. Halligan described the ebb-current as the "will-o'-the-wisp of the harbour-engineer." Without that tidal scouring effect, however, nearly all the harbours in the English Channel and in the North Sea would find themselves in very serious difficulties. He had recently carried out harbour-works at Southwold in Suffolk, where there was a small tidal river flowing down, with a tidal compartment of only 7 miles and a catchment- Mr. Carey.

Mr. Carey. area of only about 70 square miles. When the works were commenced the entrance was practically blocked; after a prevalence of southerly winds there was only 2 or 3 feet of water between the pier-heads. The piers were projected into the sea, leaving an entrance of 123 feet width. Off the harbour, at a distance of about 50 yards, there was a steep shoal or bar. The construction of the piers and the guiding of the ebb-tide effected by them had resulted in a depth of water of 16 feet at the entrance to the harbour at low water, and in the disappearance of the bar, and the internal natural scour had deepened the harbour to a very considerable extent. It had been deepened partly by dredging, but largely by the action of natural scour. He had recently devised a system[1] which might perhaps be of service in such cases—a mechanical eroder intended to be utilized where there were sandbanks and shallows, which, if thrown into a state of suspension, could be carried away beyond the zone of the harbour. He had made a number of experiments with the apparatus on the Dutch coast, and he believed it would be of great service in many cases, especially in dealing with silt and with material readily placed in suspension. Mr. Palmer's Paper was an admirable one, especially as the Author gave such full and complete data with regard to the cost of various sections of the work. If he would kindly furnish data as to the life of jarrah timber in the sea, they would be valuable. Mr. Carey had recently used jarrah for work in the English Channel and in the estuary of the Thames, but there was very little available information as to how long jarrah timber was likely to resist the attacks of the teredo in British waters.

Mr. Hudleston. Mr. F. Hudleston remarked that one small paragraph in Mr. Halligan's Paper showed that he did not rely altogether on the current alone to pick up the sand. On p. 139 he said: "When the sand, put into suspension by the waves, and slowly moving with the current along the beach, at length reaches an inlet, it is carried into the estuary by the flood-tide." That was rather interesting, as it did not quite agree with some of the remarks that had been made in the discussion.

Mr. Jordan. Mr. Wm. Leighton Jordan observed that the passage referred to by Mr. Hudleston put a different complexion on the matter from that which had been given to it by several of the speakers. He thought everybody would agree that waves raised the sand, and the sand, being raised, went away with the current. The idea of the main features of oceanic circulation being due to the

[1] British patent No. 26,442 of 1910.

Mr. Jordan.

winds was now not universally accepted, the newer view regarding it as erroneous; and, as a matter of fact, if the Australian east-coast current came from the position indicated in Fig. 1, Plate 5, it would not be so distinctly a warm current. Admiral Wilkes,[1] of the United States Navy, had first declared that stream to come from the east of New Caledonia, and Commodore Maury[2] was of the same opinion. But Wilkes's own temperature-chart showed the origin given in Mr. Halligan's Figure to be a region of cold water flowing northward from the east of New Zealand; and the "Challenger" records had since shown that there existed a great mass of water, flowing from the equator west of the longitude of New Caledonia, decidedly warmer than the water east of that longitude. Admiral Lutké,[3] of the Russian Navy, had shown that in the south-east trade-wind region of the Pacific Ocean, there was no current flowing with the wind. Mr. A. G. Findlay[4] recorded that a counter-current in the North Pacific ran steadily right against the trade-wind for two weeks. Admiral Wilkes[5] had further shown that in the region of Saint Helena, in the heart of the south-east trade-winds of the South Atlantic, little or no current was ever experienced. Finally, Major Rennell[6] had previously pointed out that experienced ship-captains knew that in the North Atlantic there was a broad stream which helped them when beating northward against the north-east trade-wind. The records by Wilkes, Maury and Lutké, merely showed the impotence of the trade-winds in the South Atlantic, the South Pacific and the North Pacific, to be the same as described by Rennell in the North Atlantic. The "Roaring

[1] C. Wilkes, "Narrative of the United States Exploring Expedition," vol. v, p. 473. London, 1845.

[2] H. F. Maury, "The Physical Geography of the Sea" (General Chart of Currents). London, 1857.

[3] F. Lutké, "Voyage autour du Monde." Partie Nautique, p. 186. Saint Pétersbourg, 1836. "En latitude de 26° nous reçûmes un vent de S.E., qui passa insensiblement à l'état de véritable vent alisé, et qui même quelquefois souffla fraîchement ; mais tout cela ne produisit point de courant ; . . ."

[4] A. G. Findlay, "A Directory for the Navigation of the North Pacific Ocean," 3rd ed., p. 1200. London, 1886. "On the Equator, in long. 175° E., a current of about 2 or 3 knots an hour ran to the eastward for 14 or 15 days, although the wind was then fresh from the eastward ; . . ." Findlay, on the same page, records that Admiral Wilkes traced the North Pacific counter-current from long. 170° E. to long. 138° W. Maury, in paragraph 401 of the work above quoted, says that the currents of the calm belt of the Pacific are very strong, and are generally found setting to the *west*.

[5] Vol. v, p. 469 of the work cited above.

[6] J. Rennell, "An Investigation of the Currents of the Atlantic Ocean," p. 115. London, 1832.

Mr. Jordan. Forties," alluded to by Mr. Halligan, created long sweeping seas in the South Atlantic, where the eastward current caused by the earth's rotation went with them; but when they met the Agulhas current coming from the east the character of the great waves changed. The current chafed against the wind, forming short, dangerous seas, but it held to its course unchecked: showing that the "Roaring Forties" had as little to do with the creation of the eastward currents of the temperate zones as the trade-winds had with the westward currents of the equatorial regions. Mr. Halligan's Fig. 1 gave correctly the main features of the Australian coastal currents, but it was certainly incorrect as regarded the region from which the warm water on the east coast was derived.

Mr. Poulden. Mr. G. E. L. POULDEN considered that there were many points raised in the Papers which younger members of The Institution would like to see thrashed out by their seniors. His experience had been gained chiefly on the west coast of South America, where he had had an opportunity of studying the matter under Mr. Adam Scott, M. Inst. C.E., consulting engineer to the Chilian Government. Most of the diagrams shown would apply to that coast to some extent if the cardinal points were reversed; and under those conditions the Richmond River would resemble one river-mouth which he had studied and helped to survey, the mouth of a comparatively insignificant river, which it was hoped to convert into an important harbour. It seemed to him that in all such cases due regard should be had to the geology of the locality and the age of the river, and the fullest investigation should be made as to what the river had been doing in geological times, and what it was trying to do now. Care should be taken to ascertain whether it was endeavouring to assist the engineer or not, and due consideration should be given to the question whether the harbour was to be designed for coastal traffic or for over-sea traffic. In the case to which he referred the harbour was only intended to admit at first vessels of light draught, the river not containing sufficient water to scour to any large extent; and it was concluded that the sea was having a marked though not complete effect in damming up the mouth. At one time the water on the bar had not exceeded 5 feet—if there had been as much as that. He ventured to think that the scour of a river had a good deal to do with the maintenance of the depth of water at its mouth, and that conclusion was exemplified by Fig. 4, Plate 6. It was stated that a great freshet in the Newcastle river occurred in 1893, and in 1896 the result of that freshet was still visible, the 5- or 6-fathom line showing that the effect lasted at least throughout 3 years, because, as he gathered, no works were carried out in the meantime to the north, and the south breakwater was extended only slowly. It would be interesting to know how the soundings had been taken. Generally his view was that the position by sextant should be plotted to about a metre, or less, of the position at which it was actually taken, no matter at what distance from the land, always supposing that the leading marks were good. Section-lines were of course more reliable, and it would be interesting to know whether the soundings on which the contours were plotted had been taken by sextant or by section-lines from leading marks. With reference to the cost of dredging, he thought it would interest engineers to know whether both deck and engine-room stores were included in the return headed "Stores," and also whether the time of the dredger going to her place of deposit and returning was included. Mr. Poulden.

Mr. Halligan, in reply, remarked that he was afraid a good deal of the adverse criticism of his Paper arose from misapprehension of the facts put forward in it. Mr. Darley had said that because the entrances to Sydney Harbour, Jarvis Bay, and Botany Bay had rocky headlands on both sides, and no adjoining sand beaches, they could not be compared with the river-entrances cited in the Paper. Careful perusal of the Paper would show that they had not been compared, but that they had been referred to as illustrating the fact that in no case on the coast of New South Wales did a broad entrance exist having shallow water, while in no case did a narrow entrance exist having deep water. The Paper had been written mainly in the hope of eliciting some explanation of these facts other than that offered by its author. To him it appeared that the north and south heads of Sydney Harbour represent the north and south breakwaters which should be built at the entrance to a sandy estuary. The fact of their extending for some distance on either side was immaterial, for the sand would travel as readily past a headland a mile long as past a point a few yards long. Mr. Darley had said that there was no movement of sand at Sydney Harbour entrance, but he had not explained how the sand in the eastern channel had accumulated, as mentioned on p. 141. Mr. Halligan was of opinion that the Paper read before The Institution in March, 1896, by Mr. W. H. Wheeler,[1] and the discussion which it provoked, completely disposed of the idea of sand being brought in from the depths of the sea: at all events, any such statement would require to be Mr. Halligan.

[1] "Littoral Drift: in its Relation to the Outfalls of Rivers and to the Construction and Maintenance of Harbours on Sandy Coasts." Minutes of Proceedings Inst. C.E., vol. cxxv, p. 2.

Mr. Halligan. backed by very strong proof, while Mr. Darley made the statement without one observation to support it. Mr. Halligan did not expect all engineers to agree with his conclusions, but he thought that before his observations were disputed, other facts and figures should be produced to disprove them. On the coast of New South Wales so many hundred observations and measurements had been made during the last 20 years, which proved beyond all doubt that the beach-sand was travelling from north to south, except in the few cases cited on p. 135, that it was not proposed to discuss the question now, unless some definite records were produced to show the contrary. In referring to the building of the Newcastle north breakwater, Mr. Darley had described how "the sand coming in from the north filled in the bight, following the breakwater, and eventually commenced pouring round the breakwater again with the flood-tide." This was exactly what Mr. Halligan contended must necessarily happen when the entrance was made so narrow as to create a high velocity for the incoming tide. Was it not quite evident that, had the entrance been sufficiently wide, the sand now drawn in at each flood-tide, would have been carried past in the littoral current? Mr. Darley said: "With regard to making the harbour wider, as Mr. Halligan suggested, it was rather wider now than the current could maintain . . ." If this harbour-entrance had to be maintained by the tidal current, then Mr. Halligan at once admitted that wide entrances were a mistake; he was of opinion, as stated in his Paper, that the less tidal current there was the less sand would be brought into the harbour to cause trouble to the engineer. The waves were undoubtedly a very potent factor in connection with the question of sand-movement on coasts where no permanent ocean-current existed, or where the currents were tidal; for then the strongest wind, which raised the heaviest sea, must temporarily cause the strongest current, and so move the largest quantity of sand. It was not, however, in Mr. Halligan's opinion, correct to say that the waves caused the sand-movement, but rather that the wind which caused the waves also created a current which moved the sand when stirred up by the waves. The propositions advanced in the Paper did not necessarily apply to the Port of Dublin, in which Mr. Griffith was interested, or to any port where the same conditions did not obtain as on the coast of New South Wales. In Dublin Bay the ebb-tide was, as Mr. Griffith had stated, faster than the flood-tide, and therefore the resultant movement of the sand at the entrance must be in the ebb-tide's direction. This was pointed out on p. 147, and Mr. Halligan might perhaps be pardoned for calling attention again to the fact that his statements as to width of entrance were not to be taken as general conclusions, Mr. Halligan. but only as applying to the harbours on the coast of New South Wales. Mr. Davis had spoken of the bars at river-entrances being formed of sand thrown up by the sea during a gale, but Mr. Halligan contended that there was absolutely no warrant for such an expression. All writers on the subject, so far as he was aware, agreed that the function of the storm-wave was to tear the beach and the shoals down and carry the sand seaward, and that such sand was washed up again during normal weather. On the coast of New South Wales sand was sometimes heaped up at the northern end of beaches, and to a less extent at the southern end during southerly gales; but, as stated in the Paper, this was due to the wind retarding the littoral current, whereby less sand was conveyed past the entrances than during normal weather. Without going into the details of wave-action to prove what must be regarded as an accepted fact, it might be pertinent to ask why the sand did not heap up, by the action of the waves, at Sydney Harbour entrance, Hawkesbury entrance, Port Stephens, Jarvis Bay, etc. The sea-bottom at each place was clean white sand similar in every respect to the beach-sand at Newcastle, the storm-waves were as large, the wind was as fierce, and the entrances had the same degree of exposure. It was impossible to believe that the storm-wave had a selective action, as must be admitted if it were desired to regard the words "thrown up by the sea" as anything but a phrase. Mr. Meik had paid him the compliment of saying that he had started to write his Paper with a preconceived idea, and had followed that idea all through the Paper. Mr. Halligan admitted this: authors generally had a preconceived idea before starting to write. The measurements of the speed, direction, volume, and salinity of the ocean-currents had certainly been made from the deck of a ship or from a boat, but the direction and volume of the sand-movement had been ascertained by observations and measurements ashore, and from careful surveys of nearly every river and harbour on the coast during a period of about 30 years. Mr. Halligan did not claim to be an engineer; and as to bringing heterodox opinions before The Institution, he was of opinion that all progress must necessarily be over the dead bodies of what were once orthodox opinions, and he had submitted his Paper to The Institution, knowing that it would be judged on its merits alone. He did not claim originality for the broad-entrance theory, except in so far as it referred to the harbours of New South Wales, where the conditions were suitable for its application. Mr. W. H. Wheeler had laid

Mr. Halligan. down, in 1896, as a general principle for the guidance of engineers designing harbours on coasts subject to littoral drift,[1] "that the entrance to a harbour should be sufficiently large to prevent any strong set into it on the rising tide, and to allow of its being filled with a smaller velocity of current into it than the flood-tide has in front of the entrance." If for flood-tide ocean-current were read, this principle applied perfectly to the coast of New South Wales.

Mr. King. Mr. C. W. KING desired to thank the members for their courteous reception of his Paper. In reply to the discussion upon it, referring to Mr. Darley's remarks as to widening the Newcastle entrance, the proposal of the present Chief Engineer was to extend both breakwaters on existing lines to such positions that the north wall would arrest the sand-travel during flood-tide from the north, so that it could be handled easily by occasional dredgings; and the south wall extension would still further protect the entrance-channel from the heavy south-easterly seas, and prevent any additional range in the harbour, which would probably occur if the north wall were extended without an addition to the south. This proposal, however, would not widen the entrance appreciably. The purpose of the comparative contoured plans up to that of 1907 was to show the beneficial effect of the ebb-tide current in maintaining the depth of channel at the existing width. In regard to the sinking of the hulks, the saving of cost was shown by the difference in the quantities of stone per lineal foot required to build the breakwater. For the 400 feet constructed immediately preceding the sinking of the hulks the quantity of stone per lineal foot (of breakwater) totalled 208 tons; whereas, over the length blanketed by hulks and iron punts, the quantity was reduced to 135 tons per lineal foot. He would point out, however, that the opportunity for this class of construction was unique, inasmuch as the wrecks of the "Adolph" and "Regent Murray," as well as the "Lindus," assisted considerably in the blanketing process. He did not suggest that the inflow of sand was due to the restricted entrance, but attributed it solely to the flood-tide current round the end of the north wall, particularly in north-easterly and stormy weather. With regard to Mr. Griffith's remark that many of the improvements were due to mechanical appliances such as suction dredgers, Mr. King might point out that the contours of 1907 showed a vast improvement over those of 1905, due very largely to the scouring effects of the breakwaters, the dredging during this period being equalized by the inflow during each flood-tide; and it was anticipated that the effect of the proposed

[1] Minutes of Proceedings Inst. C.E., vol. cxxv, p. 28.

extension of the north wall would be to reduce still further the necessity for dredging operations. In regard to the system, mentioned by Mr. Poulden, of taking the soundings from which the contour-plans were prepared, the practice of running parallel lines across the channel had been adopted, every fourth sounding being located by sextant angle off a section-line on to fixed stations at convenient spots, the intermediate soundings being interpolated with sufficient accuracy for practical purposes by keeping a uniform speed on the sounding-boat. The degree of accuracy aimed at was the plotting of the figure of the corrected sounding, covering, on a plan of 400 feet to 1 inch, the position where the sounding was taken. On a sandy bottom this practice gave the necessary degree of accuracy, but on a position covered by uneven boulders or rock formation, lines were taken longitudinally with the current, the lead feeling the bottom as the boat was allowed to drift slowly. When crossing each 100 feet section the position was taken as mentioned above, and the intermediate depth again interpolated. Calm weather was selected for the latter operation, and in important places the results were checked by repeated driftings. The accuracy of this system had recently been proved by a sweep 40 feet long, fixed horizontally at a certain depth, previously ascertained in the ordinary way as the minimum depth of the channel, and carried by a steam lighter over the portion under examination. Any depth less than that so recorded on the sweep was readily observed from the deck of the lighter. The design and operation of this sweep was under the supervision of Mr. Percy Allan, M. Inst. C.E., whose results therewith as to depth of channel concurred with those of the Author. In regard to Mr. Halligan's remarks on this port, and the statement that the bar shoaled from 22½ to 18 feet, this effect was shown on the 1905 plan where the 3-fathom contour touched the line of leading fairway towers. There still remained, however, the 22-foot navigable channel to the south of this line. The 38,000 tons of sand removed in 6 weeks had been dredged not from the bar but from the extension of the line of the north breakwater. This had been done as an experiment, in order to ascertain the possibility of arresting the inflow of sand from the Stockton Bight by dredging alone, without the assistance of an extension of the north wall. Mr. King.

Mr. Palmer, in thanking Mr. Coghlan for his kindly remarks, observed that he could not claim to be an Australian engineer by birth, education, training, or experience. He was now in practice in England, and his Australian experience, however valuable, had covered a comparatively short period. He could not see how the remarks in his Paper as to dredging could lead it to be supposed, Mr. Palmer.

Mr. Palmer. as feared by Sir Whately Eliot, that there was similarity in the physical conditions of Timaru and Fremantle. Sand-travel might exist, and might even be of equal amount, without any such similarity. He was obliged to Sir Whately for pointing out that it had been necessary to dredge away the sandbank which had accumulated at the end of the Bunbury mole. The accumulation took place subsequent to construction of the work, and Mr. Palmer had put on record, before leaving Australia, his opinion that dredging would be necessary. The dictum that Nature would do the work was a subsequent and local public enunciation. The answer to Mr. Poulden's queries was that the cost of all stores was included in the dredging return, as also was the time spent by the dredger in going to and from the place of deposit. In reply to Mr. Carey, it was to be regretted that no information had been published regarding the life of jarrah in British waters. Mr. Palmer considered that this timber could not claim immunity from attacks by the teredo, though it certainly resisted attack better than softer woods. The Government of New South Wales had issued a publication giving their experience with the timber, and Mr. Palmer believed that the results of tests made in Holland were published a few years back, though he could not find out where they had appeared. In the vicinity of Fremantle jarrah was practically not attacked by the teredo.