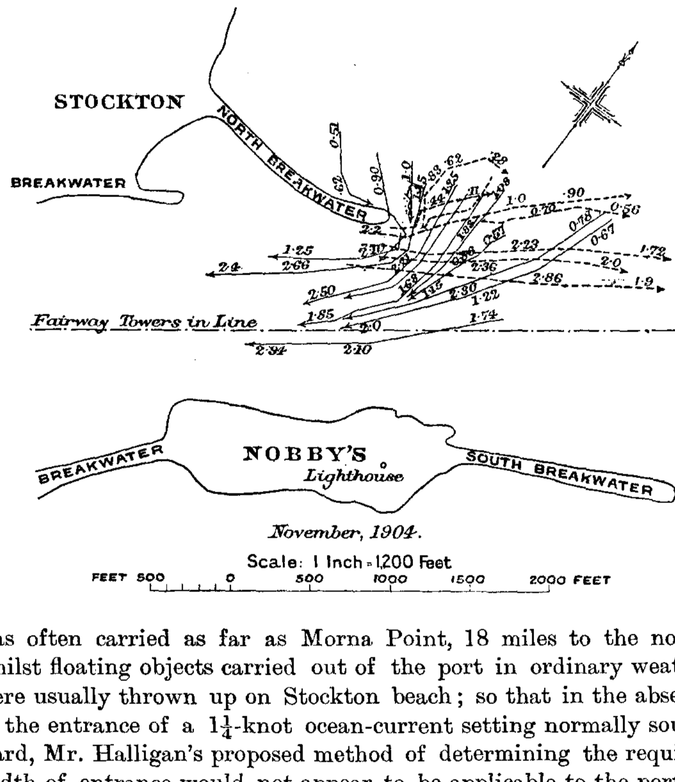
Correspondence.

Mr. PERCY ALLAN considered that the proposition put forward by Mr. Halligan, to design harbours on the common basis of 1 foot of entrance-width to 4 acres of tidal compartment, would appeal to few engineers; and as bearing on the question of the late Sir John Coode's opinion in regard to the benefit of contracted as against wide entrances, the case of Lake Macquarie, situated about 16 miles to the south of Newcastle, might be cited. This harbour had an area of 27,000 acres, and the width between the breakwaters was about 1,400 feet. There was no large volume of upland water after heavy rains, the large lake acting as a regulating reservoir and allowing of the gradual discharge of flood-water through the entrance. The works were designed in the early days of the colony, and after about £98,000 had been spent without any resulting improvement, it was decided to obtain a report from Sir John Coode: he reported in 1887 that to make an effective entrance between the ocean and the lake it would be necessary to reduce the width at the ends of the breakwaters to 200 feet, at a cost of £63,000. This report led to the stoppage of the works. Mr. Halligan stated that at Newcastle the tidal compartment was 10,288 acres, requiring an entrance at least 2,570 feet wide, as against the existing width of 1,200 feet, yet Mr. King gave the tidal compartment as only 6,500 acres, which would reduce this width to 1,625 feet; this was an entrance even narrower than obtained under natural conditions when small vessels only could enter the port, the chart at that time showing depths of but 10 feet and 14 feet respectively in the channels, and an entrance disfigured by wrecks. The later charts accompanying Mr. King's Paper also showed the many subsequent wrecks at the entrance, due, in Mr. Allan's opinion, to the then wide entrance and uncontrolled cross ebb-currents setting to the north and forcing vessels on to the much-dreaded "Oyster Bank." Again, the normal speed and direction of the current off the entrance was given by Mr. Halligan as $1\frac{1}{4}$ knot per hour to the south, but Mr. Allan would point out that the port of Newcastle was embayed by Morna Point to the north and by Red Head to the south, and the prevailing southward ocean-current was not met with at the entrance. This was clearly shown by the current observations on the accompanying charts taken by Mr. Surveyor Kenny in 1906 (*Fig. 1*) and by Mr. King himself in 1909 (*Fig. 2*), Mr. Allan.

Mr. Allan. and both charts also showed the ebb slightly to exceed the flood-tide. Again, the top leading tower of the port being situated in the grounds attached to Mr. Allan's residence, he had had exceptional opportunities during the past 3 years of observing continually the set of the current off the entrance, as clearly indicated by the soiled river-water. On the ebb-tide this ran straight out for more than a mile, gradually fanning out with a northerly set towards the Stockton beach, the soiled water, after continuous north-easterly weather, being occasionally discernible for a mile to the south. It was also a matter of common knowledge that the debris in flood-time

Fig. 1.

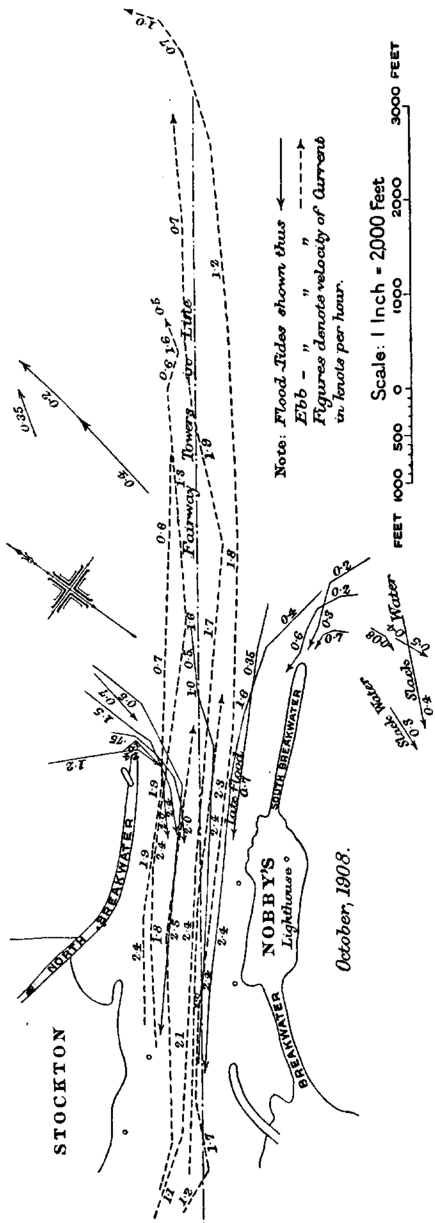


was often carried as far as Morna Point, 18 miles to the north, whilst floating objects carried out of the port in ordinary weather were usually thrown up on Stockton beach; so that in the absence at the entrance of a $1\frac{1}{4}$-knot ocean-current setting normally southward, Mr. Halligan's proposed method of determining the required width of entrance would not appear to be applicable to the port of Newcastle. Mr. Allan considered that current-observations made in a gale of 60 miles per hour were of no practical value, even though recorded to 0·3 knot, especially as the velocity of 60 miles per hour—possibly a local gust—differed from the official registration at

Mr. Allan.

Signal Hill, Newcastle, of 44 miles per hour as the maximum wind-velocity for the month of February, and 51 miles for the year 1908. While it was true that sand was brought into the Newcastle entrance with the flood-tide, Mr. Allan considered this to be due to the north breakwater having been stopped in comparatively shallow water close to the Oyster Bank; the waves breaking on this bank stirred up the sand, which was then carried into the entrance and deposited near the old end of the breakwater. With the 420 feet extension of the north breakwater now under construction, the end would be in deeper water and be so far seaward of the Oyster Bank supply of sand as materially to reduce the amount of dredging at the entrance. Mr. Halligan had, from a theoretical point of view, so questioned the design of the Newcastle entrance as to warrant some reference being made to the practical result obtained. Mr. C. W. Darley,

Fig. 2.



Mr. Allan. M. Inst. C.E., who designed the works, said, in a letter written to Mr. Allan, that on the day he arrived in Newcastle (12th June, 1867) he went out on the bar and took soundings with the Harbour-Master at that time, Captain Allen, and found only 14 feet. He also said that there was then only berthing for one oversea vessel, and one mooring-buoy for an oversea ship in the Horseshoe—a contrast to March, 1910, when more than a hundred deep-sea vessels were, at the termination of the strike, awaiting coal-cargoes. With the exception of about 185 feet of the north breakwater, now in course of construction, the works as designed by Mr. Darley had been completed, and it was doubtful whether more successful engineering and commercial results had been obtained in the construction of any artificial harbour-entrance. Since the completion of the first 3,000 feet of the north breakwater, early in 1907, many heavy gales had been experienced, yet not a single wreck had been recorded, although between then and the present date no less than 11,100 vessels, with a total registered tonnage of upwards of 20 million tons, had passed safely in and out; in fact, the coal-shipments alone for the record year of 1908 totalled more than 6 million tons. These figures did not include the local tugs, in many cases with barges in tow, which formed a not inconsiderable portion of the shipping business of the port. Vessels with a draft of more than 25 feet had left the port on a neap-tide, and many drawing 25 feet 11 inches had left at high water, the S.S. "Drachenfels" having cleared in March, 1911, carrying 10,588 tons of coal with a draft of 26 feet 10 inches. For many years the potentialities of Newcastle as a deep-sea port had been considered to be limited by the occurrence of solid rock at the entrance, which could be removed only at heavy expense. Upon taking up the position of District Engineer at Newcastle in April, 1908, Mr. Allan was requested by the then Chief Engineer, Mr. L. A. B. Wade, M. Inst. C.E., to have an examination made as to whether the rock was of such a jointy character as would permit of explosives being used without the cost of drilling; and, shortly after, a punt was moored at a point in line with the fairway towers where only a depth of 21 feet 9 inches obtained. The diver, after sending up a number of boulders, reported that he could work a bar down 4 feet without touching solid rock. A couple of clam-shell dredgers were then set to work, with the result that a test hole, excavated to a depth of 32 feet 6 inches, was found to be still in shingle. Since then upwards of 18,000 tons of chert boulders had been removed from the entrance-channel, and the depth of the port as advertised to the world had been increased from 20 feet to 23 feet at low water of spring-tides. The first additional 2 feet was mainly due to the widening of the channel by the sand-pump dredger "Jupiter," the gutter on the Green Beacon line carrying 22 feet 6 inches not being recognized by the Navigation Department in signalling the depth of water on the bar, which was based on the 20 feet then obtaining in line with the leading fairway towers. Although the clam dredgers were doing their work well, yet when the calm westerly winter weather set in, the present Chief Engineer, Mr. E. M. de Burgh, M. Inst. C.E., purposed employing a ladder dredger, which it was anticipated would have no difficulty in picking up both the large boulders and the underlying shingle. The Navigation Department being responsible for giving the draught to masters of vessels leaving the port, it was necessary—before advertising any increased depth—to determine that no projecting boulders had been left in the channel, and for this purpose a sweep had been designed by Mr. Allan which consisted of a steel pipe 10 inches in diameter and 40 feet long, rigidly connected to two 8-inch by 8-inch Oregon-pine vertical runners, spaced 25 feet apart. The sweep was placed under a steam-lighter, the vertical runners coming up on either side and passing through slots in a heavy timber frame rigidly bolted to the deck; steel guy-ropes were made fast to the horizontal pipe, passing fore and aft to keep the structure in a vertical position. The sweep was then lowered to the required depth to be tested, the depths being marked off on the vertical runners and adjusted to low water of spring-tides as the tide rose or fell, the tide-gauge readings being signalled to the lighter for every inch of variation. The width of channel was buoyed off and the lighter was steamed up and down, taking a strip of 40 feet at a time, until the whole channel had been gone over several times without touching. In using a sweep such as this, the results obtained, although on the safe side and quite satisfactory and convincing to the Navigation Department, were usually against the engineer's work, the pitching of a short vessel even in a slight sea-way resulting in a less depth being recorded than on a calm day. Mr. Allan.

Mr. Wm. Reid Bell considered that the thanks of engineers in Australia were due to Mr. Palmer for his useful record of works executed at Fremantle, a port whose importance in the Commonwealth was second only to that of Sydney. The old idea of detached sheltering breakwaters on sandy coasts seemed to have died very hard. It was difficult to understand how anyone could imagine that, with a drift alongshore induced wholly or in part by wave-action, a solid obstruction to the wave-action would permit the passage of the drift-sand, and the delivery thereof at the further Mr. Bell.

Mr. Bell. end of the protecting work, to be carried on its previous course just as if no break had occurred in the propelling force. Like many other engineers, Mr. Bell, in his day, had thought out all sorts of contrivances to train and concentrate the shore currents, say, in the fashion of a Venturi meter, with the object of forcing the drift past the breakwaters and delivering it unsettled at the other end; but, however far one went, one was brought up at last against the fact that to every shelter there must be a lee somewhere, and there must the current fail and the drifting of sand sink to the bottom. The approaches to Fremantle seemed to be well lighted, but he questioned the economy of employing a first-order light in such a situation as a leading light, particularly in a sandy channel where variations in the banks and shoals might occur from time to time. Such a variation had actually occurred at Fremantle, as a large extension of the shoal east of Middle Bank was located by H.M. ships in 1907. This shoal, carrying about 4½ fathoms, invaded the white sector of Woodman's Point light, and vessels coming in had to navigate on the border between the white and green sectors. This was not a satisfactory result for the expenditure of £7,600 plus the annual cost of a first-order establishment, although, of course, it must not be lost sight of, that, in the few years since the Woodman's Point light was established, great strides had been made in the reliability of untended lights. The instance, however, served to show the necessity for providing flexibility in systems of channel-lighting. Two or three years ago there was some desire on the part of mail-boats for a landfall light on Leschenault Point, or Wreck Point, some distance to the north of Fremantle. The currents in the offing set towards the shore for the greater part of the year, and it was contended that in the case of a high-speed ship running to time and making the landfall from the northwest, there was nothing to guide the ship to Rottnest in the event of the current setting her in towards the coast. This coast was devoid of prominent landmarks, and as it was fringed with shoals for a distance of 8 or 10 miles, beyond which the soundings deepened somewhat rapidly, the effective and economical lighting of it was a matter of difficulty. The Paper enabled an interesting comparison to be made between river-ports and harbours on the open coast. It was impossible, of course, for an outsider to range before him all the circumstances which had determined a question of harbour accommodation; but, on the other hand, the invisibility, so to speak, of local conditions to an engineer at a distance enabled him to view the matter in a different if not a clearer perspective—having regard to what ought to be done, as distinguished from

the political or local possibilities open to the man in command. Mr. Bell.
Mr. Bell therefore advanced his opinions, not so much as criticism of a good work, but as considerations to be taken account of in coming to a decision upon schemes of modern harbour accommodation. Modern appliances rendered possible, and modern requirements demanded, departures from the harbour-engineering of Smeaton, Telford, Rennie, and Watt—for Watt was a harbour-engineer. Not that the principles laid down by these masters were at fault; but the accommodation required to-day, and the means of utilizing or combating the forces of Nature had grown so that present-day harbours were problems of a different order. More particularly did these remarks apply to the questions of deepening and maintaining harbours by natural or induced scour, and to the utilization of natural as opposed to the creation of artificial harbours. The questions that had faced Sir John Coode, and later, that accomplished engineer, Mr. C. Y. O'Connor, might be taken to be sand-drift on the coast, and the utilization of the Swan River. Sir John's choice was right, inasmuch as he rejected the river and chose the foreshore in front of Fremantle, where the space for expansion was unlimited; but his scheme of piers 37 feet wide, with the bottle-neck viaduct, would have been utter waste of money for the chief port of Western Australia. It was fairly certain that had there been any sand-travel, Nature would in time have completed the work of connecting the harbour with the shore, beginning at the southern end. Mr. O'Connor's task had been a difficult one, because he had had to decide upon a harbour with an approach of more than 10 miles through a 6-fathom channel in sand in the open ocean. It would have been very valuable had information been given as to Mr. O'Connor's reasons for adopting the river in preference to the foreshore. The only light thrown on this point was the estimate of £800,000 approved in 1892, which in subsequent years expanded to nearly £1,500,000. At all events, the Swan River seemed now to have reached its development on the south-eastern side with about 5,000 feet of wharfage, while on the north side extension could be got only by reclamation on the foreshore, enclosing docks entered from the Swan River. It was unfortunate that Mr. O'Connor's and Mr. Palmer's proposals for the development of the south quays had not been carried out. As constructed the quays and sheds were cut off from the town by a railway sorting-yard. The dirt and smoke from the locomotives must alone depreciate greatly the value of the town properties adjacent. Nothing but standage should have been provided, say, for empties near the South Mole, and for fulls near the railway-

Mr. Bell. bridge, and the sorting-sidings should have been placed where the traffic from both sides of the river could have been assembled together —perhaps anywhere between Fremantle and Perth. Practically $1\frac{1}{2}$ million sterling had been spent in providing 12,000 feet of quays (equal to £121 per foot of quay), or, leaving out the outside jetties and the Rottnest light, the cost for 10,000 feet of harbour-quays might be taken as nearly £137 per foot. There was already an agitation to bring shipping up the Swan River to Perth—a step which would be of more value to the city of Perth than to the State; but the real problem was that the accommodation was limited to vessels not exceeding 30 feet draught, because with the exposure of the approach to Gage Roads, the navigation would presumably require in heavy weather at least 6 feet depth of water under the keel. Fremantle was therefore faced with the same questions as to depth which were pressing for settlement in Melbourne and Sydney. Not far south of Gage Roads was Cockburn Sound, selected by Admiral Sir Reginald Henderson, K.C.B., as the western naval base of Australia. This had a depth of 10 fathoms, and seemed to be the only natural site for a first-class port on this coast; but the sand-movements and the configuration of the sea-bed from Rottnest to Cockburn Sound must be clearly ascertained before either Gage Roads or Cockburn Sound could be fully developed as permanent national harbours. In view of the large expenditure and the limited accommodation at Fremantle, Mr. Bell considered that the best and most economical scheme for the establishment of a first-class port, unconditioned by existing interests and capable of the fullest expansion, would have been an artificial harbour on the foreshore, situated where the best access to deep water might be obtained either naturally or by dredging. As a case in point, he would instance the harbour of Burnie, in Tasmania, where an extension of the artificial harbour was about to be made from his designs. The present extension would provide 36 feet depth at low water, and the works were laid out with a view to expansion. The approaches were clear, with no outlying dangers, and the natural depth at the entrance of the complete scheme would be 42 feet at low water, with 11 feet range at spring-tides. The bottom was clay, with a covering of sand, and by reclamation of the foreshores with dredgings not less than 30,000 lineal feet of quays could be obtained, with depths up to 42 feet at low water, at a cost of £100 per lineal foot of quay, inclusive of breakwaters, sheds, and equipment. Taking the relative exposures into account, and the nature of the beds and foreshores, he considered that such a harbour, with a working-depth of at least 30 feet, could be established at a similar cost at Gage Roads, and that it would be capable of being extended in depth and in area more readily and economically than works in the Swan River. Mr. Bell.

Mr. H. A. Blomfield considered it to be a cause for satisfaction that Mr. Halligan had taken up his pen on the subject of bar harbours, how the bars were formed, and the remedy for the trouble. This branch of engineering was one of the most difficult to understand and one in which it was almost impossible to calculate results. In many cases more light needed to be thrown upon the subject. Tides, scour in rivers and estuaries, the set of the littoral and ocean currents, frequency or infrequency of floods, etc., waves, and wind-action, were all more or less important factors in the results of every interference with Nature which man attempted; and only by very close study of all these matters separately and collectively was it possible to arrive at a design for an artificial harbour which would ultimately carry out the aim of the engineer. Mr. Halligan attacked the scour theory, and in a country where there were no heavy floods during periods of 10 years or more, he had some right to do so, as it would be admitted that, unless a superabundance of upland water were present, the discharge would not clear the channel. The reason clearly was that in the ocean the sand had been stirred up and was in suspension, and the inrushing flood-tide carried it into the mouth of the river, where it was deposited. The ebb-tide, however, had not the same favourable conditions; as a rule it was, for months in a year and perhaps from year's end to year's end, a very gradual and easy flow, having neither waves nor tempest to aid it in stirring up the sand. No doubt the velocity increased to the ocean; but this velocity was only about equal to that of the flood-tide, and therefore he did not see that it could take out as much as the sand-laden water of the flood-tide brought in. Thirty years ago The Institution discussed a Paper[1] by Mr. Walter Raleigh Browne, M. Inst. C.E., in which the author argued that the flood-tide brought in more sand, silt, etc., than the ebb took out, and the velocity of the ebb-tide was stronger at the surface than in the centre or bottom; in fact that, while strong at the surface, it was slack at the bottom, and so even with an apparent rush out the particles of silt, etc., in suspension did fall and were deposited in the channel, thus not only not scouring it but in reality silting it up, because the scouring-power of any current depended Mr. Blomfield.

[1] "The Relative Value of Tidal and Upland Waters in maintaining Rivers, Estuaries and Harbours," Minutes of Proceedings Inst. C.E., vol. lxvi, p. 1.

Mr. Blomfield. wholly on its velocity at the bottom. The late Mr. Vernon-Harcourt, in the discussion on this Paper, admitted there was a good deal of truth in what Mr. Browne had said, namely, that the tidal water alone of the ebb was not able to remove the whole of the silt brought up by the flood. If, therefore, there were no floods or heavy rushes of upland water, might it not be concluded that during this period the ebb-tide did not keep the channel free by scour? And if this went on for 12 months, or, worse still, for years, then the theory of the efficacy of the ebb-tide scour must be abandoned. Mr. W. Smith also seemed to agree with this when he said, 21 years ago,[1] that the supposed effects of ebb-tide currents, guided by artificial works, should be more clearly proved from observation before the profession went to sleep over the theory; and that millions of money had been thrown away upon this time-honoured fallacy. The coastal current on the shore of New South Wales always went in the one direction, and the point was whether this current carried a quantity of sand in its course or not. With the 2-knot current always in the one direction, to the south, a very considerable quantity of sand must surely be always carried south by the current after heavy seas; and this water, given a turn obliquely on to the coast by the north-east winds, deposited its burden of sand on the beaches, and in the bays and river-mouths. This could be observed daily, as well as the denudation of sand from the beaches by the southerly or south-easterly gales; thousands of tons had been washed out by the heavy gales of October, 1910, and January, 1911. The beaches on the coast were always fed, in a gradual manner, by the north-east winds, the apparently unobtrusive action of which seemed to cause its subtle destructive power to be forgotten. One statement in Mr. Halligan's Paper, comparing (p. 142) the catchment-area of the Clarence River of 8,505 square miles, the largest in the list, with Crookhaven, of 40 square miles, the smallest, was misleading. Of the £462,000 spent on the Clarence River, £182,830 was the cost of the first scheme, most of which was discarded by Sir John Coode. Up to date, the expenditure was £283,419, but this had been devoted altogether to inside training-walls, and no breakwater work of the scheme had yet been carried out; nothing whatever had been done to help the bar, which was practically in its virgin state. With regard to Crookhaven, which had cost £9,000, this was one of the two entrances to the Shoalhaven River—occasionally the only one—and the Shoalhaven River had several thousand square miles of catchment-area. The

[1] Minutes of Proceedings Inst. C.E., vol. c, p. 201.

Crookhaven was not a river at all. The work here was almost entirely inside walling, and the breakwater had been advanced only into 8 feet of water at low water, just abutting on to a reef dry at low water; its beneficial result so far had been only to prevent the sand from the current and beach-wave action from entering the river. The comparison therefore did not hold good. From Mr. Blomfield's 5 years' experience as resident engineer on the Clarence River, he knew that the inside works were a decided advantage to the navigation of the river, and should not be disparaged; if the northern breakwater had been built to keep the sand out, there would, in his opinion, have been fully 18 feet of water on the bar at low water of spring-tides. Mr. Blomfield.

Mr. T. E. Burrows felt that Mr. Halligan had taken a great deal of trouble in compiling the information contained in his Paper, and if not agreeing with the deductions made, he considered that the subject had been dealt with in a manner worthy of the consideration of harbour-engineers. The trend of the coast-line as a whole was north-east and south-west, and the offshore current was usually no nearer the land than about 3 miles. Steamers going north always kept inshore, while those going south were usually 3 miles out or more. Mr. Halligan's contention that there was a littoral-drift current from north to south along this coast-line was, in Mr. Burrows's opinion, erroneous. No current occurred on the littoral sufficient at all times to cause any serious or regular movement of material along the shore in one recognized direction. It was shown that along the whole coast the movements observed had been in contrary directions, varying according to the locality. Mr. Halligan also stated, as a reason for the alterations from what he considered the general set of the littoral current, that the headlands at the northern ends of beaches caused an eddying southerly current at these places. This reason was entirely insufficient, in Mr. Burrows's opinion, to account for the movement of sand and other material to the north at these places. As in other parts of the world, the controlling power over the littoral drift was the prevailing heavy winds (which in this case came from the south), causing heavy seas to stir up and move the material in a northerly direction. Where an entrance or beach was protected by a southern headland, the heavy seas and winds caused an eddying current to the north of such headland, and moved the material in the immediate vicinity to the south. Mr. Halligan stated that at the Richmond River, and at other places spread over the whole length of the coast, he had found that the travel of the sand, as Mr. Burrows suggested, was to the north. It was also to be noted that where an entrance was protected by a southern headland the depth of water at the entrance was much more stable than at places not so favourably Mr. Burrows.

Mr. Burrows. situated. The Clarence River, Newcastle, Crookhaven, Bateman's Bay, Moruya and Wagonga were instances, and throughout the past 25 years, during which Mr. Burrows had been closely connected with the construction of harbour-works along the coast, he had found the bars there to show almost a continuously even depth of water. During the summer months the north-east wind was prevalent, but it was for the most part of a mild character that caused no heavy sea, and would have but very small effect on the current along the shore. It would be observed from the trend of the coast that all winds between and including the north and west points of the compass might be discarded, as they had no effect on the current or sea. The easterly wind had a very marked effect on the heaping-up of sand at the river-entrances. It blew directly on shore, and when a gale occurred from this direction (fortunately a rare occurrence in recent years) the ill effects at various ports were considerable. A south-easterly wind was the next most troublesome to harbour-engineers, and it was by gales from this direction, owing to their greater frequency, that most of the damage was done. Southerly and south-westerly winds also created heavy seas. Taking the whole action of the prevalent heavy winds affecting the sea and currents, there would be no possible doubt that the quarter from which most effect was experienced lay between south-west and south-east. The mileage of the winds from this quarter taken from the Author's Table was 30,567 miles, as against 14,898 miles of north-easterly wind. Again, taking the winds of more than 30 miles per hour, the proportion, discarding the offshore winds, was as 37·2 to 1·2. It was quite evident, therefore, that if the prevailing heavy winds controlled the movement of the littoral drift, then the movement must be from the south-west to the north-east. Mr. Halligan stated that these storms were of rare and uncertain occurrence, but their frequency was sufficiently obvious to Mr. Burrows to account for a considerable sand-movement to the north for the whole length of the coast. Where a river-entrance was protected from the action of the southerly winds, the movement of the sand at the entrance was very slight. Such entrances, from north to south, were the Clarence, Hastings, Camden Haven, Port of Forster, Newcastle, Shoalhaven, Bateman's Bay, Moruya, Wagonga and Bermagui; and though the induced or eddy current from the littoral drift set into the entrance from the north, it was an eddying current with very little power to cause any movement of the shore-material. The Clarence entrance was one of the most stable along the coast; the width on the bar was as Nature made it, but the inside channel had been diverted and drawn in to 1,450 feet. Before this was done, in accordance with the late Sir John Coode's design, the channel over the bar had a travel of about 2 miles to the north, and was uncertain in direction; and an inside crossing carrying only 7 feet at low water formed a terrible obstacle to the safe navigation of the port. By the construction of these inner works, the position of the channel over the bar had been fixed within narrow limits, and the position of the old crossing now carried more than 20 feet of water. So far from the sand being drawn into the entrance by the narrowing of the portals, there were now several million tons of sand less in it than when the existing works were completed. The breakwaters which Sir John Coode directed should be constructed first had not yet been commenced, and Mr. Burrows was confident that if these had been carried out in the first instance the entrance to this river would have required no attention from dredgers, except perhaps after one of the dreaded easterly gales. The Hastings entrance was also favourably situated as to its protection from the prevailing heavy winds, and was also a particularly stable one, usually carrying about 7 feet of water at low water. One short length of breakwater as an alignment to the channel on the southern side had been constructed, and the inner and adjacent portion of the tidal compartment was very wide and shallow. A crossing formed well inside the entrance, owing to the current of the flood- and ebb-tides being allowed to wander without direction. The width of entrance was practically as Nature made it, and there was little effect from any sand drawn into the harbour. Camden Haven and Port Forster were two minor ports where no serious attempt had been made to construct works which would affect the entrance. Some training-walls inside had been constructed, but these could not be said to have advanced sufficiently to control the current at the entrances. It was necessary, however, to draw attention to the fact that the eddying current from the main northward littoral current set south at both these entrances. The port of Newcastle at the mouth of the Hunter River was second in importance only to Sydney, and a considerable expenditure had been incurred there in the construction of training-walls and breakwaters. Protected by a southern headland standing well out, as well as by a south breakwater at the southern end of a large sandy bight (Stockton), the northward littoral main current, induced by heavy winds, was diverted under the lee of the headland and came back to the entrance along the northern beach as an eddy-current, being at this place strong enough to move material from the beach into the entrance. The other ports so protected were on the south coast, and although the movement of Mr. Burrows.

Mr. Burrows. the sand in the vicinity of each was said to be from the north to the south, these entrances, as far as their bars were concerned, had a constant and almost uniform depth of water, and any trouble to navigation arose from the cross action of the flood- and ebb-tides shoaling the inner crossing. Mr. Halligan contended that in these places, through the entrance being narrow, the sand was induced by the action of the flood-tide to enter the port, and that the scouring action of the ebb-tide was not sufficient to remove it again. Mr. Burrows certainly did not agree with this statement, as all the entrances would have closed up long ago had this been the case; the ebb-tide scour had a function—and a very active one—in keeping the entrances clear of any sand swept in by the wave-action.

Another statement to which strong exception might be taken was that the upland water of the coastal rivers might be regarded as a negligible factor in the design of harbour-entrances. The late Sir John Coode, when designing the harbour-works for the entrances at the Richmond and Clarence rivers, was informed of the occurrence of high floods on these rivers—and rightly so, as up to that time these floods, although coming at uncertain intervals, had been large factors in the making and marring of the existing channels at the river-mouths. The designs were therefore so made as to carry a flood-discharge without creating a gorge, and although there had been an absence of high floods during the past 18 years, there was, in Mr. Burrows's opinion, no doubt that such floods would recur and the accumulated deposit in such entrances as the Richmond River would then be swept out to sea and removed by the offshore current, or deposited in deep water where it would give no further trouble. Mr. Halligan also missed the main action of storm-waves in stirring up the sand and other material at a greater depth than was done in fine weather. This material so loosened was carried farther along the coast obliquely and cast up on the shore. The Paper disparaged the value of the transformation effected at the Richmond River entrance by the construction of the harbour-works there, and as these works were the only ones which had been practically completed, Mr. Burrows proposed to show that the effect of the works had amply borne out the promise of the designer, who anticipated that 12 feet of water would be obtained here at low water. As pointed out before, little or no assistance had been gained from the expected occasional flood-scour for the past 18 years, and the works had been carried out during a period extending over about 22 years; this had allowed the lodgment at the entrance of an accumulation of sand that could be removed only by a flood or by expensive dredging. The minimum depth of 8 feet mentioned by the Author had obtained for a short time after a heavy easterly sea had thrown up the sand on the bar; but practically no dredging on the bar had been necessary, the ebb-tide scour having removed the obstruction in a short time. The position of the entrance had been fixed definitely; it previously travelled over a distance of 7,200 feet and was constantly changing its position, thus causing the inner channels to become tortuous and shallow. From being one of the most dangerous entrances and one frequently impossible to navigation—on some occasions for months at a time—it had become one of the safest on the coast, and ocean steamers had been able to enter and leave at night-time, as well as to negotiate it successfully at low water and half-ebb. Mr. Burrows.

Mr. Halligan was unfortunate in his selection of the Manning River as a port to which he would apply his theory of a wide entrance. The designer of the harbour-works had made use of the northern rocky foreshore as a base for the root of the north breakwater, and the current was so trained that it would be carried along this concave wall and be always in the same direction. The ebb-tide scour was now only sufficient to maintain a channel 200 feet wide between the northern wall and the advancing southern spit. If the wide entrance were constructed clear of sand (a matter of impossibility in Mr. Burrows's estimation), or powerful dredgers were set to work to clear it, the up-river deposits would move down and fill the space so left, and necessitate constant dredging to keep it clear. The old order would return; and instead of having to clear a small area, as would be the case with Sir John Coode's design, the area requiring to be dredged would be doubled; indeed, the southern wall, as proposed by Mr. Halligan, would soon be entirely buried. A considerable quantity of sand was driven into this entrance by southerly gales; not permanently, however, as the ebb-tide was sufficient even here to cause the larger portion of it to be removed again, and the cutting-off of this supply of sand by the construction of the southern breakwater in the position designed by Sir John Coode would eventually make this entrance as safe for navigation as those carried out at the Richmond River had done. In dealing with the ebb-tide scour, Mr. Halligan had not mentioned that the time of ebb was 1 hour longer than that of flood, and that this alone would prevent accumulation of the sand in the entrance to any large extent. This effect was greatly added to by the discharge of the upland water; Mr. Burrows had seen in a moderate freshet in 1901 on the Richmond the run-out lasting throughout the whole of the 24 hours. The tide certainly rose and fell, but the surface current was strong enough to prevent any run in the direction of the flood-tide. He would

Mr. Burrows. also point out that when the tug-boat "Protector" was wrecked at the Richmond entrance in 1902, there was no local wind to account for the very heavy sea prevailing, the storm generating the sea being some distance off the land; but the south-easterly sea creating the ocean-current along the littoral was sufficient to carry wreckage and portions of the bodies of the drowned men about 50 miles north of the port. Mr. Burrows had been resident engineer on the south coast for about 15 years in charge of the harbour-works at Moruya and Bateman's Bay and other places, and subsequently district engineer for 2 years at the Richmond River, and during the latter portion of this time he had also had control of the Clarence River harbour-works; a portion of the coast, therefore, had been for a long time under his constant observation, and the harbour-works at the entrances named had been closely studied with regard to the movement of sand, as affected by ocean-currents and storm-waves.

Mr. Coode. Mr. A. T. Coode considered that it was not clear how the examples of Sydney, Botany Bay, and Jervis Bay, which Mr. Halligan cited to support his main argument in favour of wider entrances, could be made to apply to the cases of the Manning and Richmond rivers. The entrances to the former harbours remained stable apparently without any artificial works, while those of the Manning and Richmond rivers wandered up and down the coast so long as they remained in their natural state. It was difficult to believe that the determination of the width to be given to an entrance was such a simple rule-of-three sum as Mr. Halligan suggested, even though the application were confined to ports on the same coast-line. Thus, on the South African coast, the entrance to Durban Harbour would be found to have a width corresponding approximately with that given by Mr. Halligan's formula; but the success which had attended these works depended largely, it was understood, upon the dredging-operations, which according to his argument should not have been necessary. Again, at East London the distance between the mole-heads was greater than was required by Mr. Halligan's rule, so that there also, where successful results had followed dredging in conjunction with training-walls, dredging should not have been needed. At these two South African ports the tidal rise was very similar to that on the coast of New South Wales; the upland water had the same comparative insignificance, except on the occasion of freshets; and there was a considerable travel of sand. It would be interesting if Mr. Halligan would outline the methods which he would have adopted, apart from a wider entrance, to improve the mouth of the Richmond River. The criticism of Sir John Coode's remarks on the ultimate movement of shingle, and the qualification which Mr. Halligan considered should be added thereto, appeared to be based only upon observations of the power of the littoral currents on the coast of New South Wales to transport sand. Mr. Coode.

Mr. E. A. CULLEN, from experience of the harbours and rivers of Queensland, agreed to a large extent with the conclusions arrived at by Mr. Halligan as to sand-travel being the dominating factor. On the coast of the southern part of Queensland conditions were somewhat similar to those of northern New South Wales, save that the summer winds from the north-east quadrant were less pronounced, being, in fact, sea-breezes rising in the forenoon and usually dropping after sundown. The winds with greatest effect on sand-travel, therefore, were those from the south-east quadrant; and on flat, sandy beaches, with seas striking obliquely thereto, wave-movement transported large volumes of sand. The ocean-current referred to by Mr. Halligan was also experienced on the Queensland coast as far as the southern termination of the Great Barrier Reef, that was, at Breaksea Spit and in the vicinity, where shipmasters had reported a speed of 4 knots per hour at certain irregular periods; whether the current was experienced farther north outside the Barrier appeared to be uncertain. This current continued thence southward with speeds varying up to 2 knots per hour, according to season; yet, owing to the counter-currents produced by the contour of the coast and to the predominant winds, the general sand-movement was to the north. Mr. Halligan's remarks on the sand in the estuaries, on the New South Wales winds, and on the values and quantities of upland water, applied almost equally well to Queensland. The flood-tide was a potent factor in introducing sand or silt. In the Brisbane River, which discharged into Moreton Bay, with onshore winds the river-water was discoloured for 20 or 30 miles up, whilst during weather that produced no chopping wave-action on the bar the water in the river was clear enough for objects to be visible at a depth of 3 or 4 feet. Water impounded in the dry dock 18 miles up, and at rest for 24 hours, yielded a deposit which, when dry, varied up to $\frac{1}{8}$ inch in thickness: most of this was brought in by the flood-tide from the bar. Mr. Halligan's Table of ratios between width of entrance and tidal area might be added to by establishing the ratios between the cross-sectional areas of the entrances and the volumes of tidal water entering, and it would be interesting if these ratios could be furnished for the harbours cited. The river-entrances shown in Figs. 6, 7, and 8, Plate 5, would suggest that the entrance-works as executed had been designed without special reference to the Mr. Cullen.

Mr. Cullen. factors that would be dictated by systematic regularization of each river as a whole. Perhaps Mr. Halligan could state the reasons for ignoring those factors, assuming that to have been the case. Taking into account the expenditure mentioned and the results obtained, it might be considered better practice to treat similar entrances by dredging alone; it would certainly be much cheaper in capital cost.

Mr. Deane. Mr. H. DEANE wished to express his concurrence in the main arguments of Mr. Halligan's interesting Paper, and in the conclusions drawn by him. He himself had paid considerable attention to the meteorology of eastern Australia and the discharge of the rivers, particularly those of the coast of New South Wales. The rainfall on the east coast of Australia, which was rather remarkable for its high average, was made up largely of heavy falls, occasionally amounting to several inches in 24 hours, while for long periods the weather might be exceedingly dry, during which time the river-flows very much diminished. It followed from this that the discharge from the rivers could not be depended upon, as a rule, to assist the ebb-tide in keeping harbour-entrances clear. It was therefore important to avoid any set of conditions increasing the strength of flow of the flood-tide which would bring the sand in. The entrances should be kept wider than ordinary practice would dictate, and in this way there would be no tendency for the travelling sand to enter, but it would be carried past outside. Mr. Halligan was of opinion that the movement of sand along the coast was effected by the agency of the littoral current, and not by storms and heavy seas. It was evident that currents of the velocity mentioned were not strong enough in themselves to translate the sand, and apparently the sand, having first been stirred up by a wave and carried up the beach, settled on its return in a position farther on in the direction in which the current was moving; the next wave repeated the operation, and so on.

Mr. Halligan. Mr. G. H. HALLIGAN thought Mr. King's Paper was particularly instructive and valuable as showing, by continuous charts, the sand-movements taking place from time to time, as the result of work done in a sandy entrance. This diagrammatic method was much more effective than masses of figures, though the contour-lines were rather close, and the result was rather confusing owing to the small scale to which the plans had had to be reduced; if one contour, say the $3\frac{1}{2}$-fathom line, were selected and emphasized on each diagram, ideas could be fixed much more readily. Before discussing the plans it would be as well to state that at the Newcastle entrance

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there was an ocean-current with a normal velocity of $1\frac{1}{2}$ to $1\frac{3}{4}$ knot per hour. It flowed from north to south, except during southerly or south-easterly gales, when the surface direction was retarded and sometimes even reversed during the period of the gale. These occurrences, however, were so infrequent and of such short duration that their influence upon the ocean-current might be neglected. The result of the current flowing always in one direction was to convey sand along the beach from north to south until it arrived at the entrance to the estuary; the flood-tide then conveyed most of it in, and the ebb took some of it out again, depositing the greater part of it in the form of a bar at the river-mouth; from there the current was continually taking part of it into suspension and carrying it away to the south. When the island of Nobby's was joined to the mainland, and the south breakwater was built, it formed a trap to catch this sand, which had extended farther and farther out, on the north side, as the south breakwater was continued. The object of the north breakwater was to stop this sand from entering the estuary, but a cursory glance at the $3\frac{1}{2}$-fathom contour-line would show that this result had not been achieved. There was practically no change in the $3\frac{1}{2}$-fathom line between 1896 and 1905, notwithstanding the fact that 2,500 feet of north breakwater was built during that time; the reason being, in Mr. Halligan's opinion, that the ocean-current still conveyed the same quantity of sand to the entrance, and that it was still met by the same trap—the south breakwater. After 1903 dredging was carried out, and the following figures showed the quantity of sand dredged from the Newcastle bar between the 1st July, 1904, and the 30th June, 1910:—1904–5, 60,100 tons; 1905–6, 156,340 tons; 1906–7, 183,075 tons; 1907–8, 399,050 tons; 1908–9, 573,050 tons; 1909–10, 506,404 tons; total, 1,878,019 tons. The result of this dredging was shown in Figs. 9 and 10, Plate 6, and unless dredging was continually kept up, the entrance must again become as bad as before. It was now proposed to extend the north breakwater another 420 feet, in the hope, as Mr. King said, that the sand-drift would be kept within easy control; but no reason was given for this optimism. The same quantity of sand must be brought to the mouth by the southward ocean-current, and as it did not heap up behind the north breakwater it must cross the entrance; it could only do this by entering with the flood-tide and in part coming out again on the ebb, and the same old trouble would have to be overcome by resorting to the expensive process of dredging. Unless the north breakwater was continued so far out as to be farther east than the south wall, and the entrance was

Mr. Halligan. made so wide that the velocity of the flood-tide would be less than that of the ocean-current, Mr. Halligan could not see how any improvement in the existing state of affairs was possible. It would probably be cheaper to stop building the breakwater, and accept the annual charge for dredging as inevitable, than to extend the north breakwater as proposed.

Major Harts. Major W. W. HARTS, of the Corps of Engineers, U.S. Army, remarked that Mr. Halligan's long experience of 35 years on the east coast of Australia would naturally enable him to speak with much authority as to the physical conditions of that locality; and his study of ocean-currents, sand-movement, winds, and tides during his connection with the Government of New South Wales had given him excellent opportunities for drawing conclusions as to the harbours and bars along the coast. Some of these harbours were singularly like several of those on the coasts of the United States, where the entrances were more or less obstructed by sand-bars, of which Major Harts had some knowledge. It was, therefore, with considerable hesitation that the following comments on Mr. Halligan's conclusions were submitted. His statement that sand was brought into the harbour on the flood-tide, and then deposited so that all of it could not be removed by the ebb-tide, led to the belief that he regarded all harbours on sandy coasts as sand-traps into which, little by little, sand was carried in suspension, never to be removed by other currents at ebb-tide. The fact that many harbours of considerable size on sandy coasts had remained open and in a condition of equilibrium for many generations, and perhaps centuries, would indicate that there was something faulty in Mr. Halligan's conclusions, and that there must exist in all such cases some balance between the forces tending to fill up the harbour and other forces tending to enlarge and deepen it. That this balance was an absolutely fixed one few engineers would dare to say; but that it existed only few would probably feel inclined to deny. When the depth over the bars of harbours in their natural state was insufficient for navigation, the controlling works placed by engineers in the entrance introduced a new element, which disturbed the old equilibrium and produced new conditions, giving rise to a new balance between the contending forces, the results of which, if the works had been properly designed, were a greater depth and better facilities for navigation. If greater depth were desired, experience at many harbours showed that a narrower outlet would be necessary, to assist in securing the conservation of the energy of the ebb-tide and a greater control of its field of action. Mr. Halligan's assumption that greater depths would follow a widening of the entrance, and consequent reduction of the velocities of the currents, seemed contrary to experience elsewhere. Major Harts agreed that the upland water was of no importance in the average case, but he felt inclined to differ from the statement that the effect of the velocity of the ebb was not somewhat greater than that of the flood. The greater power of the ebb-tides for transporting sand, and thus improving the conditions within a harbour and at its entrance, had been relied on by many eminent engineers; and their numerous works showed that their views had not been sufficiently erroneous to cause disappointment. As a harbour filled from a limitless supply of water on the rising tide, the water entered from the sea without being confined to any special direction, and after entering it spread out in all the irregularities of the bay and its many indentations, creeks, and channels. Not only was this water not directed as it entered the harbour, but it flowed with a constantly decreasing hydraulic radius until the harbour was filled, so that the currents, after they passed the entrance, diminished in velocity. When the tide fell, the water flowed out with a constantly increasing hydraulic radius at a constantly increasing velocity, and the direction of the flow was controlled by the banks and channel; so that it seemed reasonable that its action at the entrance should be more effective than on the flood-tide. The favourable results already achieved in the improvement of bar harbours were usually attributed to direction of the ebb flow towards the proper place, and to prevention of any waste of energy as it emerged from the outlet. The great depths that had been found inside the bar in many harbours indicated that this process of ebb scour was more nearly what actually happened, than that the harbour was being gradually filled from without by sand that could not escape. The crescentic shape of the bar obstructing many entrances indicated that the ebb-tide, laden with sediment, deposited its load only when its velocity had been checked by the quieter water in the ocean. If these views were correct, it would seem that Mr. Halligan's statement that breakwaters or jetties should be as far apart as possible could not be accepted without question, but that there was an artificial width for the entrance at each harbour which would produce a new and more favourable equilibrium, with greater depths and with lessened tendency to shoal. In the case of Newcastle Harbour, the shoaling which had taken place between the breakwaters indicated that the balance between the filling and eroding forces had not yet been properly secured. Major Harts's comments were necessarily based

Major Harts.

Major Harts. on descriptions and maps of a coast with which he was unfamiliar, but the successful application of certain fundamental principles to the improvement of American harbours led to the conclusion that some of Mr. Halligan's statements were not sufficiently supported for general acceptance.

The map of the Newcastle entrance in 1866 (Fig. 2, Plate 6), before any improvement had been attempted (with the exception of the breakwater connecting Nobby's Island with the shore), showed the harbour to be similar in many respects to the usual entrance through a sandy coast, where the apparent effort of the littoral sand-bearing currents and storms was to close the entrance with sand, against which the tidal flow through the bay struggled to scour sufficient channel-capacity to accommodate the inflow and outflow of the tide. Although all of the forces at work about this entrance were not known, Mr. Halligan's Paper demonstrated very convincingly that the littoral current across the mouth was from north to south. Although severe storms came sometimes from the south-west and south-east, the prevailing winds came from the north and north-east, and usually set up a current along the shore in their direction. This current aided to some extent the permanent ocean-currents flowing in the same direction, and it was therefore natural to expect that the main sand-movement would also be in that direction. A study of the various maps illustrating Mr. King's Paper tended to confirm this conclusion. Upon the construction of the south breakwater it appeared that this sand-flow was more or less interrupted, and, although the tidal currents kept the channels open, there was apparently a constant tendency to deposit sand on the north spit, due to such interruption, and thus to encroach upon the channel. That might serve to explain, at least in part, the deflection of the line of deepest water toward the south in the years 1887–1909, an action that was still continuing, judging from Mr. King's reference to the tongue of the 5-foot contour, shown by the 1909 map. From an examination of the map of 1896 this action seemed to have been useful in contracting the entrance and directing the tidal currents to such an extent that the least depths over the bar had been upwards of 24 feet at that time. Then, too, there were indications several years before, as shown by the map of 1887, of the commencement of a "swash" channel, which by 1903 had deepened to more than 30 feet opposite the end of the north breakwater, thus permitting the escape of a considerable volume of the ebb-currents and consequent shoaling in the channel. All indications pointed to the conclusion that the north breakwater should have been built first, and the channel have been narrowed thereby, to increase the velocities opposite and beyond the east end of Nobby's Island. Until this breakwater was long enough to cut off entirely the sand-movement into the entrance, or to divert it sufficiently far out to enable the cross currents to carry it by the entrance, there did not seem to be much hope of relief from the expensive dredging now found necessary. The construction of the north breakwater along the north spit had apparently been beneficial in protecting the entrance to some extent, but the decrease of depths between the north and south breakwaters would indicate that the ebb-currents of the bay had not been concentrated enough to control this tendency. Further, the entrance opened now to the north-east, thus inviting a flow of sand into the entrance instead of across the ends of the breakwaters. It would therefore seem that increased depths by natural erosion could not be expected unless the north breakwater were extended and the entrance were further narrowed. It was to be regretted that the physical features of this entrance were not more fully described, as the foregoing conclusions might very likely be modified by a closer study of the natural characteristics of the entrance. Major Harts.

Mr. T. W. Keele observed that if Mr. Halligan were correct in his facts and the deductions he had derived from them as the result of 35 years' experience in the service of the New South Wales Government as a hydrographic surveyor, then it would be quite evident that engineers, the world over, had been designing and carrying out harbour- and river-improvement works on entirely wrong principles; and the waste of time and money through their neglect and incompetence must be enormous. It would be interesting to see how far Mr. Halligan's facts were in accord with the observations of others. In his remarks on monsoonal ocean-currents, he laid great stress on the influence of the north-east wind, and quoted from Mr. Dannevig's Paper in order to prove that it was the prevailing wind. The Table he relied on showed the average travel of the winds that blew from the cardinal points each month, from which he concluded that "with the exception of the westerly winds which have no great influence on the coast of New South Wales, the north-easterly are the prevailing winds, as regards number, wind-mileage, and duration." This was all very well as far as it went, but something more was required in order to determine the influence of the winds, and their effect upon ocean-currents and sand-movement. Mr. Dannevig had calculated the final resultant power for each month, and for the year, in order to Mr. Keele.

Mr. Keele. ascertain the total "drift energy" which he had set forth in diagrams. He said :[1]

> "It will be noted that from November to March, the winds blow persistently from the sea and during May to September in an almost opposite direction; April and October are peculiar to themselves, and of a neutral character. . . . The yearly resultant or normal drift is interesting as regards direction and extent, it is in accord with the meteorologist's contention as regards the general ingress of the lower atmospheric layers from the pole to the equator, but it is contrary to a popular idea which is based upon the importance of prevailing winds (with us from the north-east). The yearly resultant coincides to within a couple of degrees with the local magnetic deviation, and its relationship to the coastline might be noted."

With regard to the yearly resultants Mr. Dannevig said :[2]

> "In comparison with their average—the yearly normal—they show individually considerable differences, yet with one or two exceptions they all point north with an easterly or westerly tendency as the case may be."

This was sufficient to show that the resultant "drift energy" of the winds and of the sand-movement was to the north, and not to the south, as stated by Mr. Halligan, and that the westerly winds must have a considerable influence on the littoral current from May to September, during which it was pushed out seaward, its effect on the sand-movement thus being practically nothing. When the winds were reversed and blew from the sea, although the littoral current was pushed over against the shore, its effect became nullified by the strength of the dominant southerly winds, which, as Mr. Halligan himself had shown, retarded and ultimately reversed the littoral current, with acceleration of the northerly set existing close in shore. In view of this, it would have been interesting to know what the late Sir John Coode would have thought of Mr. Halligan's suggestion that his statement that "the ultimate movement of shingle is always to be found in the same direction as, and never against, the heaviest seas" should be qualified by the addition of the words "on a shore where there is no continuous ocean-current in one direction." Mr. Halligan also sought to show that the sand in the estuaries must have come from the sea-coast, and have been carried in by the flood-tides. There could be no doubt that this was so to some extent; but not exactly in the manner he would infer. Before any works were commenced, the rivers, during periods of drought, were almost closed at their mouths by the sand-spits making over towards the headland on either the north or the south side. These spits extended for miles in some instances,

[1] Proceedings of the Royal Society of New South Wales, vol. xli, p. 37.
[2] *Ibid.*, p. 39.

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where the rivers ran almost parallel with the coast in their lower courses; but during the continuous wet seasons, lasting several years, when the annual rainfall over the watershed was persistently above the average, the rivers were in a constant state of fresh or flood, and the sand-spits and beach-terraces were cut away for a mile or more from the mouth, breaches in the beach-terraces being made at other places. On the subsidence of the floods, the entrances and breaches in the beach-terraces, being wide open and fully exposed, were at the mercy of the sea during onshore gales, and enormous quantities of sand were driven in by the waves. Sometimes, as at the Tweed and Macleay rivers, this caused complete choking of the lower part of the river for several miles, and compelled it to make a new outlet. On a recurrence of drought, the sand-spits gradually made up again, and small freshets, when they occurred, had to cut their way in tortuous courses along the old channels to the original mouth, or, in cases where they could not do this, an entirely new channel was formed, leaving the old one permanently reclaimed, and ultimately raised by wind-blown sand to the level of the surrounding country. When the harbour-works were commenced, there were large accumulations of sand which had been driven in from the sea in the manner described, and, as the training-walls progressed, the sand became imprisoned: it had lain there ever since, awaiting the flood-season, which would assuredly recur, when it would be swept out bodily into the ocean. The channels having been permanently fixed and protected by walls, no further breaches could be made, and although during droughts a tendency for bars to form at the mouths would recur, and where works were unfinished some sand might be driven inside for a short distance, the conditions were altogether different from what they had been originally. In an improved river like the Richmond or the Hunter, no sand would ever again be forced far into the estuary. The extensions of the breakwaters well out into deep water had demonstrated that, even at the termination of one of the most protracted droughts ever experienced in the State, the rivers were able to clear themselves with little assistance from dredging. The amount of dredging required during droughts would depend entirely on the depth required to be maintained at the entrance.

Under the heading of "Tidal Currents" Mr. Halligan made some extraordinary statements, which showed conclusively that he had yet to learn a great deal about the action of the tides and the influence of the upland water upon them, and their combined effect upon sand-movement. He was evidently unaware of the fact that, Mr. Keele. although he might have found the velocity of the ebb- and flood-currents at certain times to be equal, the ebb ran out longer than the flood; and that, when it ceased to do so, the entrance shoal ultimately closed up entirely, and it could be reopened only by a flood. This was the invariable action of any river in its natural state during periods of drought, or when the fresh water had been abstracted from the main channel, either by diversion into a channel having another outlet, or by impounding the water in large reservoirs in the uplands. The fact that a river kept open at all was a demonstration of the superior influence of the upland water—no matter how small the quantity might be—on the ebb-tide, thus enabling it to counteract the influence of the flood-tide. Mr. Halligan's observations on the relative densities of fresh and salt water appeared to have been of a superficial character, otherwise he would have noted a fact ascertained long ago, that the flood-tide, in its passage up a river, pushed its way along the bottom owing to its superior density, and thus raised the fresh water above it; the latter continued its flow to the ocean, the tendency being to make the gradient steeper towards the mouth while the ebb was running out, and to increase its scouring effect. It was evident, therefore, that Mr. Halligan's advice to engineers to eliminate the area of the watershed, and the supposed scour of the ebb-tide due to upland water, from the design of an entrance with a view to improvement of the harbour, would deprive them of the dominant factors, and the result could not be other than disastrous. It was so long since a succession of wet years had been experienced on the east coast of Australia, that Mr. Halligan appeared to have become pessimistic, and to view everything from the standpoint of drought. It was a fact that since 1893 there had been a serious decline in the rainfall of the coastal region of New South Wales; for 17 years no serious floods had occurred, and very few freshets, the rainfall having been almost continually below the average. During the 5 years ending in 1893, however, when the rainfall was continually above the average, the rivers were constantly swollen, and it was during that period that most of the works were commenced, and the training-walls and breakwaters enclosed large areas of sand in the manner already described.

With regard to Mr. Halligan's contention that wide entrances were required, and not the narrow ones which so many engineers had advocated in the past, Jervis Bay, to which he referred on p. 141, was a land-locked bay with no river or considerable stream running into it. It had an area of 39 square miles of water 30 feet or more in depth, the 5-fathom contour-line running close to the shore all round the bay. Mr. Halligan seemed to be quite unaware Mr. Keele. of the true cause of the bay constantly maintaining its depth, namely, that during onshore gales it became surcharged with water, forced in by the heavy seas driven by the wind, and held up against the shore at a considerable height above the mean level of the ocean. The configuration of the coast-line on each side of the entrance presented a concave outline to the sea, which tended to produce a gorging effect on the waves, and materially assisted in surcharging the bay. In the effort to restore equilibrium, an under-current was generated from the shore all round the bay, which, running along the bottom radially towards the entrance, became concentrated there, with great scouring effect. That this action was taking place was shown by the contour-lines on a chart of the bay being wrinkled or corrugated, the furrows all pointing towards the entrance. The depth at the entrances of Botany Bay and Port Jackson was maintained in a similar manner, and a similar action was taking place at every bay and indentation along the coast, whether land-locked or otherwise, or whichever way it might be presented to the onshore winds, whether from the north, east, or south. This action alone accounted for the ability of these bays to clear themselves of sand. It was astonishing that Mr. Halligan could not see that an analogy was impossible between the natural harbours he had mentioned and tidal rivers subject to floods. Mr. Keele had already explained what the action was in such rivers under drought and flood conditions, and it was unnecessary to labour the subject further than to say that, in his opinion, the "banks of marine origin" which existed inside the entrances and were so much objected to under present conditions by Mr. Halligan, would, under the conditions advocated by him, certainly expand, both horizontally and vertically, into excellent sheltered beaches, where surf-bathing might safely be indulged in; but the shipping would unfortunately be eliminated from the harbour. In conclusion, Mr. Keele hoped that the authorities would permit of no departures from the designs of Sir John Coode, and other marine engineers of experience, on the lines advocated by Mr. Halligan; in his opinion such departures would only end in complete failure.

The Institution was indebted to Mr. Palmer for another interesting Paper on an important engineering work carried out by the enterprise of the youngest of the Australian States. His excellent Paper on the Coolgardie waterworks in 1905 had placed the members under an obligation to him, and it was fitting that he should have undertaken the duty of placing on the records of

Mr. Keele. The Institution the history and details of this second of the great works which constituted a lasting monument to the foresight and ability of his late chief, Mr. C. Y. O'Connor. It was now evident that a wise decision had been made to provide a harbour by solid works at the entrance to the river, rather than an outer harbour connected with the shore by an open viaduct. Had the latter scheme been adopted, it would have been found, even at the present time, too small to accommodate the shipping that traded to the port. Thus, the arrivals at the port of Fremantle in 1894 amounted to 406 steam or sailing ships with a total net registered displacement of 337,820 tons; by 1904 these figures had increased to 845 ships with a displacement of 1,517,791 tons; and in 1909 the figure was 1,573,757 tons. Mr. Palmer stated that the present harbour could, at moderate expense, be made to accommodate 50 per cent. more shipping than in 1904–5. The time was not far distant, however, when even this limit would have been reached, and consideration must then be given to a proposal submitted to the Government of Western Australia in 1904 by Mr. Keele, namely, to remove the railway- and road-bridges shown in Fig. 3, Plate 7, provide for an efficient steam-ferry service for the road-traffic between North and South Fremantle, make connection between Fremantle and Perth by a railway on the south side of the river, and then open up the Swan River by dredging as far as Freshwater Bay. Probably the general public of the State—and certainly most people outside of it—were not aware that the State possessed, inside the bridges, a waterway capable of being opened up by dredging into a splendid channel, gradually expanding at Freshwater Bay and Melville Water into a land-locked harbour, which even now embraced an area of $3\frac{3}{4}$ square miles with 18 feet or more at low water, $2\frac{1}{4}$ square miles with 24 feet or more, and $1\frac{1}{2}$ square mile 30 feet to 70 feet deep at low water. This would be sufficient, if some shoals were removed, to provide a safe and sheltered anchorage for the whole fleet of war-vessels on the station, in addition to providing wharfage for all shipping likely to visit the port for a great many years to come. The present proposal was to dredge a channel 350 feet in bottom width, and not less than 30 feet in depth at low water, up to the deep water at Freshwater Bay: this channel was to be subsequently widened when required to the full extent, which would be nowhere less than 700 feet in bottom width, expanding to 1,000 feet or more as the deep water was reached after passing Rocky Bay. The sides of the channel were to be lined with a rubble wall $8\frac{1}{2}$ feet high along low-water line. The area between the walls and the shore-line was to be reclaimed by the dredgers, and as the Government already possessed about five-sixths of the frontage to the river, the reclaimed areas would, in the future, be exceedingly valuable. This proposal was the result of an investigation made by Mr. Keele, at the request of the Government of Western Australia, to determine the best site for a graving-dock. Seven sites had been proposed at one time or another, three of which were within the present basin below the bridge, while the others were between the bridges and Rocky Bay. None of these sites, however, was considered by him to be so suitable as a new site which suggested itself at Butler's Hump, on the western shore of Freshwater Bay. The total cost of the complete scheme, to include the dock and naval station, was £1,460,000, and he claimed that it fulfilled all the conditions laid down by the Admiralty, namely:—a depth of water sufficient to allow of docks and basins being placed so low as to admit at low water of spring-tides the largest naval ships at what might be considered "damage draught"; spacious and well-sheltered anchorage, of an area sufficient to accommodate a large number of vessels; natural protection from an enemy's fire; a central position on the coast-line with ready and convenient means of communication with manufacturing districts particularly, and with all parts of the country generally; and finally, close proximity to a well-protected watershed or harbour. The proposal had remained in abeyance up to the present time, probably on account of the interference which would result with direct communication between north and south Fremantle by the removal of the bridges; but no parochial consideration should have been permitted to stand in the way of opening up the wide and deep water of the river to navigation, thereby conferring directly and indirectly on the whole community benefits which could not be overstated. Mr. Palmer, made no reference to the question of the graving-dock, which, as appeared from the annual reports of the Fremantle Harbour Trust, it was finally decided, in 1908, to construct at Rous Head, at the commencement of the South Mole, and opposite the 6,000-feet mark shown in Fig. 3, Plate 7. The necessity for a work of this description was no doubt felt severely, but the site selected would certainly be found inconvenient in the future, situated as it was right at the entrance to the basin. The docking and undocking of vessels would be a serious inconvenience to shipping entering or leaving the port, and, notwithstanding any breakwind which might be erected, the exposure during onshore gales would be exceedingly great: moreover, the dock would be fully exposed to the direct-aim fire of an enemy's guns.

Mr. King.

Mr. King. Mr. C. W. King considered that Mr. Halligan's Paper contained very valuable data on questions connected with bar harbours on the New South Wales coast, and would be of great assistance in considering the design of future works. The inflow of sand into rivers and harbours should be considered in conjunction with the reduction of wave-range. To solve the former question completely would, in some instances, defeat the solution of the latter. As Mr. Halligan remarked, each case must be considered on its merits. With regard to the proposed ratio of 1 foot of entrance-width to 4 acres of tidal compartment, he would suggest that the discharge-area of the entrance-channel, and also the effect of the waves in stirring up the sea-bed, would be of grave importance in determining the position of the outer works. The mean tidal current through the Newcastle entrance was about $1\frac{1}{2}$ knot per hour during spring-tides. Adjacent to the north breakwater this current was accelerated to 2·4 knots per hour, as shown by recent current-observations. The fact that these velocities were greater than that of the ocean-current clearly accounted for the inflow of sand now being contended with. Operations, however, were in contemplation, and partly in progress, to increase the maximum depth from 23 to 30 feet or more. These operations, when completed, would increase the discharge-area, and incidentally they should decrease the mean velocity of the tidal current and the inflow of sand. He had observed that at Newcastle the inflow of sand was very much greater during heavy weather than in smooth, owing, as Mr. Halligan said, to the storm-wave tearing down the beaches and conveying the sand seaward. There was also the action of the wave on the sea-bottom in the shoal water adjoining the coast. Thus, if the tidal current was in excess of the ocean-current, the inflow of sand naturally increased during stormy weather. He was of opinion that if the entrance possessed sufficient discharge-area to reduce the tidal velocity below that of the ocean-current, the width and depth being proportioned as the consideration of each case might determine, then the breakwater works constructed on such principles would largely reduce the inflow of sand caused by the action of currents. A neutral line would also be reached, seaward of which the wave-action would be at such a depth that the disturbing force on the sea-bed would be reduced to a minimum, and landward of which the wave-action would disturb the sea-bed and cause the heaping up of a bar. Observations made by Mr. King on a sandbank 29 feet below low water, and exposed to waves 27 feet high, showed no alteration in depth after a heavy gale, and he considered that the neutral line would be in the vicinity of 5 to 6 fathoms. The question of diminishing the wave-range was also of

Mr. King.

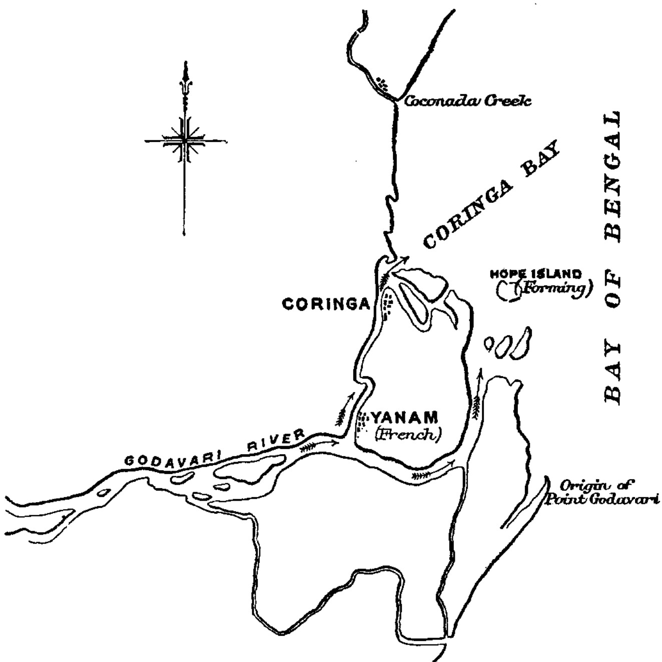
great importance in harbours with wharfage and moorings immediately adjacent to the entrance-works, and in such instances he considered that a proportion of sand-dredging must frequently be provided for, to allow of the diminution of range. Thus, at Newcastle a wider entrance than that shown would allow the swell to enter still more freely, the distance between the harbour and the extreme entrance-works being too short to allow for sufficient wave-traps to decrease the range to a safe limit. In many river-entrances the wharfage lay miles away, and under these conditions the range inside need not be taken into consideration. In such cases Mr. Halligan's proposal merited very careful consideration in the design of future works, with a view to overcome the tendency of the sand to travel up-stream and to form the crossings which appeared so frequently on the rivers mentioned.

Mr. Larminie.

Mr. J. C. Larminie thought that a few particulars of a part of the Coromandel coast where the conditions were very similar to those prevailing at Newcastle, although on a smaller scale, might be of interest. The port in question was Coconada (about 300 miles north of Madras), second only in importance to Madras on the east coast of India, and with the best and safest anchorage in the Bay of Bengal. Following the successful completion of the Godavari irrigation-works and the extension to Coconada of the East Coast Railway (about 1894), the trade of the port had increased enormously, but all merchandise had to be conveyed to and from the shipping in open boats of shallow draught. The anchorage, about 5 miles out in a north-easterly direction, was well sheltered from east to south by the peculiar long tongue of land known as Point Godavari (*Fig. 4*). Its formation was comparatively recent, and was entirely due to the silt-deposits from the Godavari River, combined with the travel of sand northward due to the southerly littoral currents. An old survey of about the year 1853 showed that, at that time, the Point had only just begun to form (*Fig. 3*). The trend of the mouths of the Godavari was northward, as shown, with the result that the vast quantities of silt brought down in floods had led to the shoaling up of Coringa Bay and the formation of numerous islands (*Fig. 4*); while the discharge of the silt-laden water seaward, meeting the littoral current and the sand travelling northward, had led at the same time to the gradual formation and growth of this long low spit, also in a northerly direction. A map of the bay about the year 1891, taken from the Marine Survey, was shown in *Fig. 4*. By that time Point Godavari had reached its present northerly limit; but meanwhile its effects on the bay within had been marked and peculiar, being precisely similar to what might often be noticed on

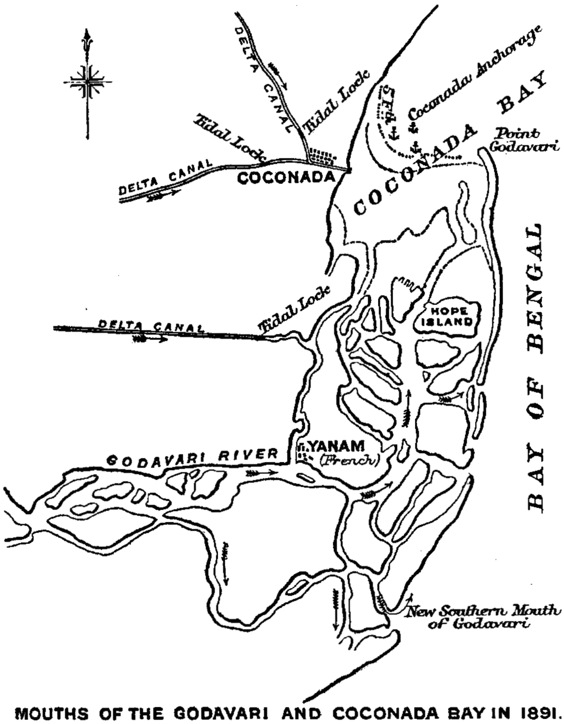
Mr. Larminie. the down-stream side of a river-groyne placed at an unsuitable angle; that was to say, scour was set up in the rear, owing to the reversed direction of the river-current. In this instance the tidal and littoral currents impinging on the eastern face of Point Godavari swirled round the point into the bay southward and westward, where, meeting the sandy coast, with its south-westerly trend, they originated the littoral current in that direction and its accompany-

Fig. 3.



ing travel of sand, which was the origin of all the trouble at the mouth of Coconada River. In regard to the bay generally, this action resulted in an improvement and general lowering of the bed towards the coast and southward. The so-called Coconada River was originally nothing but a salt creek, extending inland in two branches, which carried off some of the Eastern Delta drainage. In its upper reaches, however, about 4 miles and 2 miles from the coast respectively, were situated the terminal locks of two of the Delta main canals, whereby communication was established with the richest producing portion of the district. It consequently became necessary from an early period to maintain communication between the river and the anchorage. Wharves were constructed, the river-slopes were revetted and the river-mouth was fixed by short lengths of training-jetties. The usual result—an advance of the foreshore—followed, accompanied by the formation of shoals and a bar across the river- Mr. Larminie.

Fig. 4.

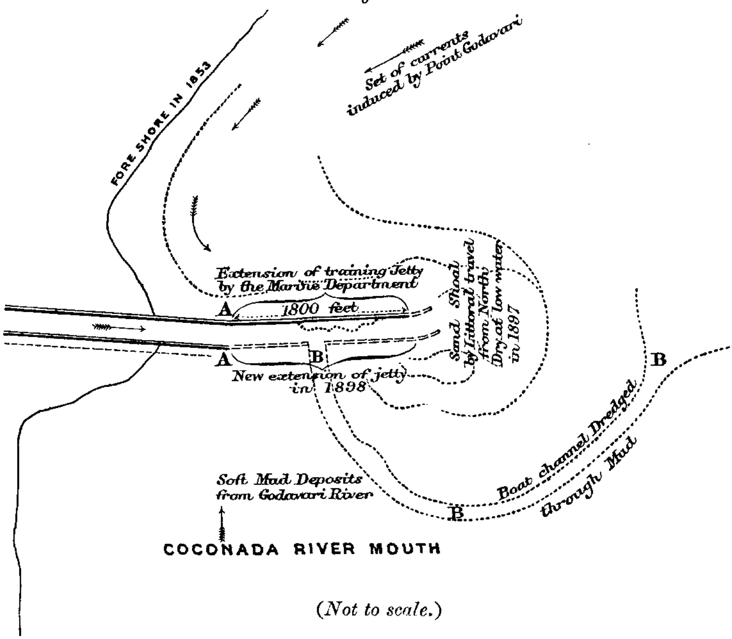


MOUTHS OF THE GODAVARI AND COCONADA BAY IN 1891.
Scale: 1 Inch = 10 Miles
MILES 5 0 5 10 15 MILES

mouth, involving constant dredging, with the imperfect appliances then available. Up to about the year 1876 the work was in charge of the Public Works Department, but it was then transferred to the Marine Department. At this time the right and left training-jetties were of about equal length, terminating at A A (*Fig. 5*). With the idea that, by extending the north jetty, the travel of sand along the beach from the north would be checked and

Mr. Larminie. excluded from the river, the Marine Department gradually carried out this work, the result being that, by 1896, the trade of the port had become seriously hampered by the formation of the shoal indicated (*Fig. 5*). This blocked the river-entrance completely, and, overlapping the channel right round to the south, necessitated the dredging of the circuitous channel B B. At this stage, Mr. Larminie was deputed by the Government of Madras to report

Fig. 5.



(*Not to scale.*)

on and devise a remedy for the inconveniences complained of by the mercantile community. The gist of that report was that the state of affairs was entirely due to the extension of the left jetty about 1,800 feet in advance of the right jetty; that so long as the ends of the two jetties had remained nearly in line, the scour of the ebb-tide had maintained a fairly deep channel, which was even still maintained, down to the present termination of the right jetty; and that, were the latter extended to the same length as the left jetty, the scouring effect would then be concentrated on the bar. The proposal was approved by Government, and the results had fully justified it; for, no sooner had the right jetty been extended and the gap at B closed, than a marked improvement in the depth on

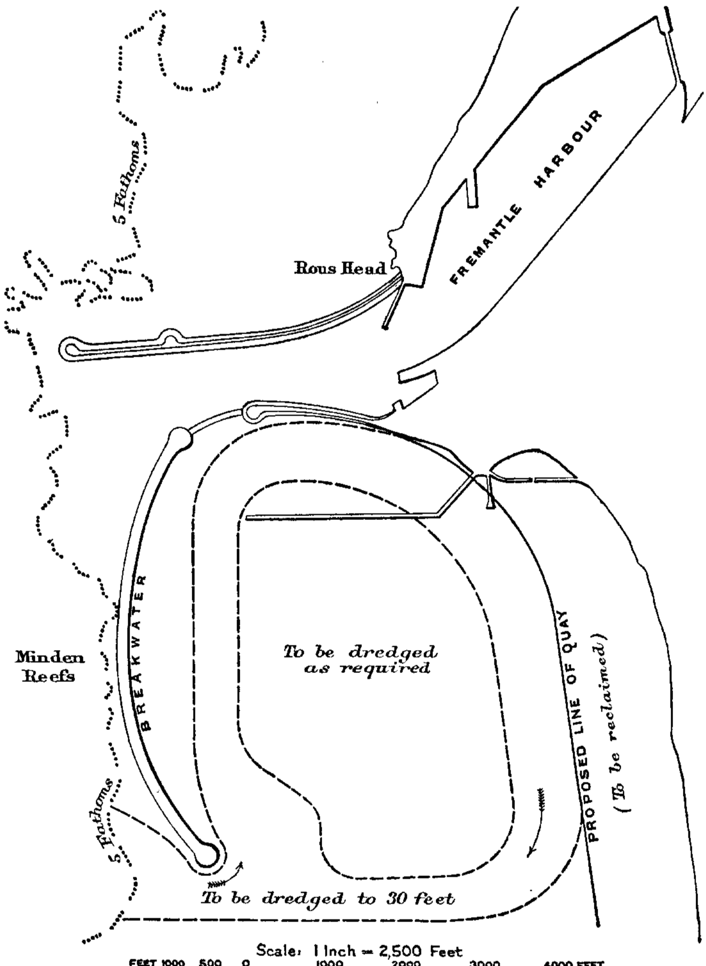
Mr. Larminie.

the bar took place. At the same time he urged that, no matter what proposal was adopted, the ebb-tide scour, unaided, was insufficient to keep the bar clear, and that the provision of a suitable suction dredger was imperative. At Coconada the tidal range was about $5\frac{1}{2}$ feet, while the basin within the bar was simply that comprised in the 5 miles of canalized creek before alluded to. The formation of Point Godavari would seem to confirm Mr. Halligan's contention (p. 136) that sand-movement was chiefly due to the littoral current, aided, as at Point Godavari, by the south-west monsoon prevailing from May to September, which, owing to the trend of the east coast along the Northern Circars, became a long-shore wind. As already noted in regard to the extension of the Coconada right jetty, Mr. Larminie's experience of ebb-tide scour was that it was by no means a will-o'-the-wisp as contended by Mr. Halligan; but the latter's deductions in regard to the connection of flood- and ebb-tide currents with the littoral current appeared to be very sound, though much would depend on local conditions. A narrowed entrance, no doubt, would head up the flood-tide, causing increased inward velocity; but this increased inward velocity would be some little distance within the entrance, removed from the coastal current, on which, in consequence, it could exercise but little draw. On the ebb, the reverse would take place, the discharge being delayed and scour over the bar ensuing, during a portion of the ebb-tide at all events. This was the explanation of what had actually occurred at Coconada, where the sand accretion shown along the left jetty had been actually removed by the ebb-tide scour. In the three instances of wide entrances given by Mr. Halligan, as he remarked, the north heads projected eastward considerably; the littoral current and sand-drift, therefore, were carried well clear of the entrances. It would require a very considerable indraught to divert the sand-travel from the southward, and consequently the entrances might be narrowed, if necessary, without injurious effect. The sand deposit on the north-east shore of Botany Bay might be from the Cook River. From Mr. Halligan's description it was not easy to infer whether it was really from this source or was carried in during south-easterly gales. As already remarked, there was also some similarity between the conditions at Coconada and those at Newcastle, as described in Mr. King's Paper; at all events, the latter port furnished conclusive evidence of the value of training and a narrowed entrance. Taking 1 foot of entrance-width for every 4 acres of tidal compartment, the width should be 2,570 feet, against an actual width between the breakwaters of 1,200 feet; while the improvements which had resulted were as traced by Mr. King. Better results

Mr. Larminie. might perhaps have been attained had the ends of the two breakwaters been aligned on a bearing about due north, the breakwaters being run due east. As constructed, their north-easterly trend was calculated to facilitate the entrance of sand from the Stockton Bight; but the extension of the north breakwater, to a point bearing due north from the end of the south breakwater, would check this tendency, and Mr. Larminie considered that the latter should not extend beyond such an alignment in respect to the north breakwater.

Mr. Lefroy. Mr. G. A. Lefroy did not see stated, in Mr. Palmer's Paper, the engineering reasons, if any, which had decided the late Mr. C. Y. O'Connor's scheme in the river as a better site for the Fremantle harbour-works than the magnificent one in Gage's Roads, the advantages of which had been recognized by competent authorities since the earliest days of the settlement in 1829. The north mole as built was in the most exposed position in which it could be placed, as regards the weather, the heavy winter gales, which did all the damage in Gage's Roads, ranging from north to north-west, after which they rapidly abated. Any other direction for the mole which inclined more to the south-west would, in his opinion, place it in a better position as regarded the prevailing heavy weather. For instance, if a single mole from Rous Head on a curved line in a south-westerly direction, and of the combined lengths of those described by Mr. Palmer, had been built instead, it would have ended on the Minden Reefs at the edge of the 5-fathom bank, and with a deep-water entrance; and the winter freshets of the river would probably have counteracted any sand-travel from the north into the south end of the roads. The scheme shown in *Fig. 6* had been suggested by him, in 1910, with a view to provide, in addition to the present inner harbour, an entrance or outer harbour of sheltered water with an area of about 400 acres, ranging in depth from 10 to 31 feet to the natural bottom. Arthur's Head (Fig. 3, Plate 7), being of sandstone, could have been formed into a short training-mole for the south side of the river. Mr. Palmer did not give the water-area of the harbour available for the wharfing and laying-up of ships; it seemed to be 128 acres gross, the area dredged to 30 feet at low water being less than 100 acres. Taking the figure £1,353,970, given in the Paper as the cost of the harbour described, the accommodation had cost at least £12,000 per acre. If the entrance or outer harbour-works had been laid out somewhat as Mr. Lefroy had suggested, the cost would very probably have been less than £3,000 per effective acre, and the wharves or quays would have been capable of far greater expansion than under present conditions would be possible, having regard to relative costs. Taking into consideration the able reports and recommendations with regard to a harbour for the port of Fremantle, from the late Sir John Coode and from others well qualified to give advice if not so well known, Mr. Lefroy.

Fig. 6.



FREMANTLE HARBOUR: EXTENSION PROPOSED BY MR. LEFROY, 1910.

it might possibly be that this scheme—so costly per acre of effective water-area provided—had been decided on more through political influences than on engineering grounds. The last Annual Report

Mr. Lefroy. of the Harbour Trust Commissioners, for the year ended the 30th June, 1910, said:—

"The heavy gales experienced this winter have given the two moles a severe buffeting, and the blow of the 20th July caused a rather serious washaway on the northern face of the north mole, near the outer end. At this spot the mole is faced with heavy granite blocks, and the sea swept this protective coating completely away at one spot, and bored a hole nearly halfway across the mole. Repairs were, however, quickly taken in hand, and are well on towards completion. To provide against any serious washaway of this portion of the mole again, it has been decided to build a parapet of granite blocks along it, to give a natural protection to the clawing-down action of the seas thrown up during heavy gales. The south mole has suffered in several small spots, but these have been in no case serious, the damages being easily repaired."

The Commissioners gave the ships which entered during the year as 672 in number with a tonnage of 1,925,548 tons, the cargo handled being 628,757 tons.

Mr. Methven. Mr. CATHCART W. METHVEN had read with great interest the Papers by Messrs. Halligan and King. They appealed specially to him, because not only had the subject with which they dealt occupied him for a very large portion of about 45 years' experience in questions affecting the improvement of the navigation of sandy estuaries and rivers, and the opening-up of heavily sand-barred rivers and lagoons in South Africa, but also the rivers of New South Wales appeared to resemble very closely in their conditions several rivers in South Africa with which he had been connected professionally during the latter 22 years of his practice. There was also a particularly close resemblance, in many respects, between the problem which had to be dealt with at Newcastle and the problem at Durban, for the solution of which he had been mainly responsible. In some cases, also, he gathered, the coastal conditions as regarded sandy beaches, and ocean and littoral currents, were also strikingly similar, though he believed he was correct in stating that while the South African coast was a rising one, the coast of New South Wales was subsiding, with the result that great natural harbours were formed, such as Sydney, Botany Bay, Jervis Bay, etc., which in South-East Africa were almost entirely absent. Mr. Halligan's Paper was none the less interesting and useful because some of the conclusions were open to criticism. Indeed, Mr. Methven was bound to say that with some of them he entirely disagreed; and he had little hesitation in attributing the failure in some of the cases to attain better results, as well as the natural maintenance of deep water at the mouths of the great lagoon harbours, to causes totally different from those assigned in the Paper. Nor could he agree with its author's conclusions as to the establishment of any ratio between the area of the tidal compartment of a river or lagoon and the width of the entrance, which might serve as a safe guide in fixing the width of entrance desirable in other cases. A much safer comparison would be between the tidal volume and the sectional area, which in a certain material—sand, for instance—it might be capable of maintaining. But in that case also, owing to the variations in the material of the beds of rivers and lagoon-entrances, as well as other important conditions, it would be impossible to establish any ratio which would be of the least use in designing the proper width of entrance. The best guide, and the only one approaching reliability, was the sectional area which the tidal volume available in the particular case under consideration could maintain naturally at a point far enough within the entrance to be comparatively unaffected by the seas; and if this was ascertainable, then, at all events, it might safely be concluded that the same tidal volume would not maintain an equal sectional area nearer the sea, where it had to encounter outside forces and a continual deposition of sand. It should not be overlooked, then, that the form this deposit took would be largely controlled by the relative position of the works, as well as by outside influences; and that form might be insusceptible of removal by tidal influences, as had been the case at one period at Durban, owing to the long overlap of the southern beyond the northern work. The simple reason was that those influences, where they existed, might be dissipated by improper design of the entrance-works, as regarded width, direction, or relative length. The reference to scour as a "will-o'-the-wisp of the harbour-engineer" was one which he feared it would be very difficult to justify; for if it were not scour which had kept open some of the rivers to which Mr. Halligan referred in their primitive condition, before artificial works were resorted to at all, he must show what the force was. Mr. Methven hardly thought Mr. Halligan would deny that if there had been no inflowing and outflowing tide, the rivers except in flood, would have closed up altogether, and solid beach would have formed across the mouths. But he did agree with Mr. Halligan if he meant only to imply that the scour in some of the cases he named, on account of its comparatively small amount, could not be relied upon, however well trained by works, to keep open a navigable entrance of sufficient width and depth without the aid of dredging. This was just the point which had to be determined, in deciding whether an entrance with a navigable depth was to be created by scour alone, induced by training-works, or by scour coupled with dredging, or practically by dredging alone. It was difficult, with-

Mr. Methven.

Mr. Methven. out more information than Mr. Halligan gave as to the available tidal volumes in the cases he cited, to speak with certainty. Taking, however, for instance, the Richmond River, the area of the tidal compartment was given as 6,800 acres only, and in the absence of more definite information as to the exact rise at this port, it might be assumed that the tidal range at springs was 5·5 feet. The average rise within the tidal compartment, depending of course on the condition of the entrance, and the internal regime of the river, might probably not be more than, say for argument's sake, 3 feet, in which case the volume at springs would be about 33,000,000 cubic yards. That was a wholly inadequate tidal volume to maintain anything like a good navigable depth in an entrance 1,100 feet wide, and therefore dredging on a large scale would be necessary. Yet Mr. Halligan suggested that this state of matters could be remedied by increasing the width of the entrance to 1,700 eet. In the same way he proposed to bring about the deepening of the Manning River entrance by widening it from 800 feet to 1,500 feet, and, but for considerations of internal tranquillity, he regarded 1,760 feet as a preferable width. He quoted the late Sir John Coode's recommendations in 1885, and referred to that engineer's expectation that the scour from the tidal compartment of this river would, unaided by dredging, secure a "true and uniform channel." Mr. Methven took it, however, that what was required was not only a true and uniform channel, but a channel of sufficient width and depth to take in vessels of the greatly increased draught of the present day. This was even less likely to be attained by the means proposed by Mr. Halligan than by those recommended by Sir John Coode. In these cases of rivers of comparatively small tidal capacity, the method of treatment had changed completely since 1885, with the development of the sand-pump dredger, and it was now proved beyond doubt that, while it was advisable to utilize as far as possible such means of tidal scour as might be available, so as to minimize the cost of any necessary dredging, the entrances should be designed with due regard to a proper relationship of the works to the contour of the coast in the vicinity, and to any outside currents which really mattered; they should moreover be made not wider than could be maintained by dredging to whatever depth was required; and at the same time the reduction of seas entering between the piers should also be effected wherever possible. At the port of East London, in South Africa, this had now been recognized. The existing entrance there had also been designed by Sir John Coode, and for the purpose of utilizing the tidal scour it had been originally made far too narrow to admit of the safe entry of vessels such as had to be accommodated now. Mr. Methven therefore, recognizing that the available scour—in that case amounting only to about 1,330,000 cubic yards—was practically a negligible quantity, had advised that this difficulty should be faced squarely, and that the problem should be reduced to one purely of dredging. The works had therefore been so disposed that, while providing an entrance 600 feet in width, the northern work could readily be extended to reduce that width, should the dredging to maintain it at a proper depth be found excessive. On the other hand, at Durban Harbour, where the tidal capacity of the lagoon was about the same as at the Richmond River, namely, 33,000,000 cubic yards, the works had been designed to utilize to the utmost the whole of the available scour, while dredging had been resorted to, as recommended by Mr. Methven, to supplement it. This had been done with great success, the combined natural and artificial forces acting in one channel now giving a reliable depth of about 36 feet at low water of spring-tides, where originally the scour—untrained, and dissipated over a wide area, sometimes in several channels—could not maintain even 6 feet at low water with any regularity. Scour was a very important agent in all these cases where it was available: thus, with works still only partially constructed in 1893 at Durban, and left at that time, owing to political and other influences, in a very imperfect relationship to each other, the average low-water yearly depth on the bar had been increased by scour alone from 6 feet 1 inch in 1882 to 13 feet 8 inches in 1892; for no bar-dredging whatever had been carried out up to that date. Since then the works had been brought out level with each other, the entrance had been narrowed to 600 feet, and persistent dredging was carried on; with the result that the largest mail-steamers now entered and left the port at all states of the tide. In assisting and maintaining the work of the dredgers, the scour had been of incalculable value, and it would be folly to ignore this fact. Mr. Halligan seemed not to have discriminated sufficiently between the totally different cases of natural deep-water harbours and shallow-mouthed sand-barred rivers. There was no comparison between the physical conditions of great lagoon harbours—such as Sydney, with a natural entrance 4,900 feet in width and a depth of 90 feet, Botany Bay, with an entrance 3,467 feet wide and 60 feet deep, and Jervis Bay with one 11,590 feet wide and 120 feet deep—and rivers such as that at Newcastle, and the Richmond and Manning rivers. To argue that because a certain relationship existed between the entrance-widths and areas of these natural deep-water lagoons, therefore a similar relationship should be established at the mouths

Mr. Methven. of the sand-barred rivers, was to take up what Mr. Methven feared would be found to be an untenable position. If he was not mistaken, the coast immediately outside these lagoon entrances consisted of high headlands with deep water close inshore, where the disturbance of sand, and its transportation by means of the surf from the prevailing seas and the surf-currents set up along the shore, was infinitesimal compared with the movement which took place along ordinary sandy beaches. Mr. Halligan laid great stress on the exclusion of sand from within the entrances by making them so wide that the flood-current entering would be of less velocity than the littoral sand-bearing current. The velocity of the sand-bearing littoral currents, as he stated, seemed to range from about $1\frac{1}{4}$ to $1\frac{3}{4}$ knot per hour—or, say, from 1·4 to 2 miles per hour. It was not clear, however, whether these figures referred to the ocean-currents, properly so called, or to the eddy-currents induced by them immediately along the shores. In any case, the bottom velocities of such currents would not exceed about half this amount, or, say, 0·7 to 1 mile per hour, and would only just move sand on the bottom. The currents close inshore in shoal water were generally a good deal slower than those farther out, and their main work was to convey sand which had been placed in suspension by the surf. The actual impact, however, of a surf which was at all oblique to the coast-line—as in New South Wales it appeared to be—had a considerable effect, and the surf-current set up by it along the sandy beaches was no doubt the main transporter of sand, as it was in South Africa, where the conditions appeared to be very similar. This action of the surf, and of the waves of translation at the shallow mouths of the rivers, taking place in water highly charged with sand, was the main cause of the conveyance of sand within the entrance-works, or into the flood-current entering the river. To increase the width, as recommended by Mr. Halligan, until the flood-current between the works actually fell below the very low velocity of the littoral current outside, would merely mean the provision of an extensive trap for sand, and necessitate vast dredging-operations, which, even if successful, would entail very serious expense. The advance of the work on the travel side of the entrance beyond that on the opposite side, as also recommended, in order to ensure the littoral current carrying the sand clear of the southern wall, would be to fall into the very error which Mr. Methven had had to oppose so strenuously at Durban. Such a proceeding would only vary the form of the sand-trap within the entrance, and induce a large deposit of sand under the lee of the longer work, diverting the navigable channel and making the entrance infinitely more dangerous. Ample illustra-

Mr. Methven.

tion of this from actual experience had been given in Mr. Methven's Paper on the Harbours of South Africa.[1]

It had often appeared to him that many of these bar problems were unduly complicated by the unnecessary elaboration of investigations into wind-force, variations and velocities of currents, shifting shoals, etc., and by the many bogies sometimes raised by the layman, and, with all due respect, he might also add, occasionally by the seaman. There were in most cases certain broad principles, the consideration of which should prevail, even to the neglect sometimes of minor forces, such as sluggish littoral currents with no scouring-power and with no effect, except as regarded the transportation of sand in suspension, that would materially affect the result of the works. Even in regard to transportation of sand these currents were only aiders and abettors, as it were, of the much more powerful and effective surf-currents set up by the seas, acting perhaps obliquely, on the sandy coast. In the present case, though speaking with the diffidence that arose from want of opportunity to make personal investigations of the rivers under discussion, he thought that less theorizing on the relationship between the flood-current into the river and the ocean-currents outside, and more reliance upon the experience gained in such cases of the effects of modern dredging-plant properly applied, would speedily result in much greater improvement. Mr. Halligan gave little information as to the power of the dredging-plant in use at the harbours mentioned; but, in referring to the Richmond River, he stated that in 3 years, from June, 1906, to July, 1909, 252,040 tons of sand were removed from the bar and inner crossing by dredging, at a cost of £4,180; and he somewhat naively added, "but no improvement is reported in the depth at either place at the end of the period; in fact, rather the reverse." This quantity represented about 84,000 tons per annum only, at an annual cost of £1,393, and unless there was some error in the amounts quoted, the dredging-plant was clearly inadequate. These works at Newcastle were cited as "another example of the erroneous idea that contraction of the entrance causes a scour of the ebb-tide in a river where there is no permanent upland water." Mr. Methven was somewhat at a loss to understand Mr. Halligan's precise meaning here, because it appeared to him that the contraction of the entrance would certainly increase the velocity of the ebb on the bar, provided the entrance were not reduced so much in width as to exclude water from the tidal compartment. At Durban he had reduced the entrance-width

[1] Minutes of Proceedings Inst. C.E., vol. clxvi, p. 31.

Mr. Methven. from 1,100 to about 750 feet, and it had been afterwards reduced still more, to 600 feet, on the advice of Sir Charles Hartley and Sir John Wolfe Barry, for the express purpose of increasing the scour on the bar—a step which had Mr. Methven's entire approval, provided this width was considered sufficient for safe navigation. The result of this action, coupled with the dredging-operations, which were persistently carried on in the open sea whenever the weather permitted, had been entirely successful. The dredgers used at Durban were of a very powerful type. The first of them, the "Octopus," with 1,200 tons hopper-capacity, had been built to his specification by Messrs. Simons and Company, of Renfrew, and had a suction-pipe 42 inches in diameter. Others of similar type, of larger hopper-capacity, but otherwise with practically the same arrangement and pumping-power, had been supplied afterwards by the same firm. The "Cetus," the largest of these, with a hopper-capacity of 3,000 tons, usually filled her hopper in about 40 minutes, and an ordinary day's work was five to six loads, or about 15,000 to 18,000 tons per day, including depositing about 3 miles off. This was the only class of dredging-plant capable of dealing really effectively with these large bars. Economy in its use must be effected by the proper design of the entrance-works, and the resulting full use of any available natural forces. Mr. King stated in his Paper that the dredging-plant at Newcastle consisted of a dredger, "Jupiter," capable of filling a 750-ton hopper in 20 minutes, and of performing an average day's work of 3,000 tons. Here again, for such a work, the plant was obviously of insufficient power, to say nothing of the excessive width of entrance of 1,200 feet for a river with this tidal capacity, and discharging apparently across a sandy littoral. There was a discrepancy between the figure given by Mr. Halligan and that given by Mr. King as the area of the tidal compartment, the former stating it as 10,280 acres, and the latter as 6,500 acres. But, whichever it was, the width of entrance appeared to Mr. Methven to be out of all proportion, and would mean a very heavy expenditure for dredging if any material improvement in depth was to be effected. The contour-lines also, on the charts of the river-entrances which accompanied the Papers, indicated unstable conditions probably due to excessive width. Mr. Halligan, in concluding, said with reference to the Richmond and Hunter rivers: "In short, it must be admitted that, in the only two cases on this coast where contracted entrances have been tried, the expected results have not been achieved." Mr. Methven hoped that Messrs. Halligan and King would forgive him for saying that in the light of the facts disclosed by their Papers, there was no cause for surprise at this, even although, judging from the original condition of the Hunter River at Newcastle, as shown by the charts of 1816 and 1866, the conditions before the works were commenced did not appear to be so severe as they were on the east coast of South Africa. Mr. Methven.

Mr. W. T. Olive was glad to see that the effect of the river at Newcastle in time of high flood was recognized as being a scouring action; thus on p. 150 it was stated that large quantities of sand were swept well out to sea and dispersed in deep water. He could not see how, with such large catchment-areas—in this case 8,000 square miles, compared with 10 square miles of tidal basin—it could be otherwise. Mr. Palmer, in describing the West Australian rivers, stated on p. 159 that the volume of their waters was so small that the rivers were unable to do more than occasionally clear their mouths of extraneous sand; while on p. 162 he said that the northernmost of the lakes discharged into the sea, the opening being maintained by the River Murray, which in heavy freshets cut through the sand bar at Mandurah. Whilst it was not possible to generalize, it appeared to Mr. Olive that where rivers flowed into harbours having narrow entrances the ideal of the harbour-engineer should be to head up the river during the flow of the tide and release it on the ebb. If that could be accomplished by sluicing-basins or otherwise, the full benefit of the land-water would be realized; in other words, whatever would conduce to a greater velocity during the ebb-tide than during the flood-tide was beneficial to the maintenance of depth and the avoidance of dredging. He was quite in accord with Mr. Halligan's remark that each case must be treated entirely on its merits, and therefore disagreed with his suggestion, for the design of future harbours, of endeavouring to establish a fixed ratio of harbour-entrance to tidal compartment. The Paper was valuable, inasmuch as it did not scruple to point out errors in the past. Mr. Olive might draw attention to the new proposal for extension at Cape Town, South Africa, which was, to impound a water-space of 431 acres by a mole 8,550 feet long, with a single opening of 350 feet. This space received the washings of a large town (all the storm-water drains delivering into it), despite the fact that a large dock of 12 acres, excavated in rock, had to be abandoned some years ago, after great expense, for the sanitary reason that there was no means of changing the water. It was hoped, however, that this would be effected occasionally by flood-water, as was the case at Curl Curl and Narrabeen lagoons, mentioned on p. 129. Mr. Olive.

Mr. Price. Mr. JAMES PRICE, while considering that Mr. Halligan's Paper gave an interesting summary of facts relating to natural and artificial harbours in New South Wales, and to sand-movements along the coast, thought the conclusions drawn from these facts were hardly in accordance with the views of engineers who were concerned with estuary harbours in the United Kingdom. In the former country it appeared that the main factor in sand-movement on the coast was the ocean-current from north to south—assisted or impeded by the surface currents set up by the wind acting on the surface of the ocean—the tidal currents being negligible, as they set straight on shore. From this it was concluded that the ocean-current carried a quantity of sand, which it conveyed into a harbour when the tidal current at the entrance flowed at a greater velocity than that of the ocean-current. Why should this be? The quantity of water flowing into a harbour each tide was the tidal volume of the harbour less the inflow of river-water for the period of rise of tide; and the sand bearing a certain ratio to the sea-water, a fixed quantity of sand would be brought in each tide, independently of the velocity of the current at the entrance. Again, the quantity of water running out at ebb-tide would be the tidal volume plus the river-water; and provided the entrance-channels were sufficiently narrow to make the velocity such as would lift the sand deposited on the bottom, the harbour would be self-cleansing. If Mr. Halligan's theories were correct, harbours with natural entrances should have their tidal areas reduced by reclamation, so as to reduce the velocity of the currents at the entrance to less than that of the ocean-currents; and artificial harbours would be constructed with wide entrances, for the same reason. It seemed more natural to assume that the ocean-currents were charged with sand picked up near the shore by wave-action, the part of the current nearer in being the most heavily charged; then converging training-walls run out to sea caused the flood-tide supply to be taken from deeper and cleaner water, and prevented the sand and gravel of adjoining beaches from entering the harbour. The comparison of entrance-width with tidal area could not lead to any very definite results; it would be necessary to take the depth into consideration and compare the sectional area of the entrance with the tidal volume of the harbour. In order to arrive at a correct estimate of the river-water, the volume and duration of winter floods should be considered, rather than the catchment-area. The Table on p. 257 gave approximately the conditions affecting the currents at eight different places in Cork Harbour at half-tide, with an ordinary winter flood. The first four sections were of artificial channels; of these three required

Mr. Price.

CORK HARBOUR CHANNELS.

		1	2	3	4	5	6	7	8
Distance from Cork	Miles	0	1	2½	3½	7	11	13½	15
Width	Feet	200	300	360	360	1,000	3,500	3,000	5,000
Maximum depth	,,	26	23	24	24	59	37	100	74
Sectional area	Square feet	5,200	6,200	7,700	8,400	45,000	110,000	175,000	210,000
Flood	Cubic ft. per sec.	300,000	330,000	340,000	376,000	403,000	418,000	568,000	570,000
Tidal area	Acres	44	126	440	570	4,500	5,600	13,400	14,000
,, volume .	Millions of cubic yards	0·8	2	7	9	55	86	212	221
Mean current from flood .	Ft. per sec.	57·7	53·2	44·1	44·8	8·95	3·8	3·24	2·72
,, ,, ,, tidal volume	,, ,,	12·3	16·8	30·9	50·2	166·05	96·2	136·76	117·28
,, ,, ...	,, ,,	70	70	75	95	175	100	140	120
,, ,, ...	Knots per hour	0·69	0·69	0·74	0·935	1·72	0·985	1·38	1·18
Surface current	,,	1	1	1⅛	1¼	2½	1¼	2	2
Siltage per annum	Inches	3	8	8	0	0	0	0	0

Mr. Price. maintenance-dredging, the fourth was maintained by the natural scour of river and tidal water. The last four were natural channels maintained chiefly by tidal currents, the last being at the harbour's mouth. It would be observed that in the upper channels river-water was the more important, while in the lower channels tidal water performed most of the work of cleansing. Thus the river-water acted indirectly on the entrance-channel by keeping the upper reaches clear to admit tidal water. If Mr. Halligan's theories were correct, Cork Harbour ought to have silted up long ago. The harbour faced the prevailing wind, the ocean- and flood-tide currents made towards the mouth at a velocity of about 1 knot per hour on the surface, and the velocity of the current in the entrance-channel was 2 knots. In place of silting, the depths were improving in the natural channels, and only about half of the artificial channel required maintenance-dredging. The velocities of the flood- and ebb-tide currents were about the same, but the duration of the ebb-current was about 7 hours to $5\frac{1}{2}$ hours of flood-current. The velocity of the ebb-current within $\frac{1}{2}$ hour of low water was sufficient to lift small gravel from the bottom and in 36 feet of water in the entrance-channel. This sea-gravel appeared only in small quantities about 1 mile inside the mouth. The river-water brought down mud and peaty matter, part of which was deposited when the sectional area of the channel became too large for the quantity of river- and tidal water available.

Mr. Rossbach. Mr. WILLIAM ROSSBACH considered that Mr. Halligan had brought together a large amount of information as to ocean- and river-currents, winds, tides, etc., which would be of considerable value to the engineers dealing with the rivers of New South Wales. Should, however, some of his deductions be correct, the position in regard to the partially-constructed harbours there became very serious, as would be manifest from an inspection of the accompanying Table, showing the widths between the breakwaters of the various rivers as designed, and as they should be, according to Mr. Halligan's formula of 1 foot width to each 3 acres of tidal compartment. Especially was the matter serious in view of the Works Department having expended about a million and a half sterling on these partially-constructed entrance-works: but in Mr. Rossbach's opinion the great differences existing between the conditions of the various rivers had not been recognized sufficiently by Mr. Halligan, and as a result some of his deductions were unwarranted. The following particulars would show how varied were the conditions. The true rivers, which did not fall into wide estuaries but came abruptly on to the coast, were the Tweed, Richmond, Clarence, Bellinger, Nambucca, Macleay, Hastings, Manning, Hunter (Newcastle), Crookhaven and Moruya.

Mr. Rossbach.

River.	Author of Design being carried out.	Width of Entrance as designed.	Width by Mr. Halligan's Formula.
		Feet.	Feet.
Tweed	Mr. C. W. Darley	500	1,667
Richmond	Sir John Coode	1,000	2,267
Clarence	Sir John Coode	1,400	11,333
Bellinger	Mr. C. W. Darley	500	547
Nambucca	Mr. C. W. Darley	500	910
Macleay	Sir John Coode / Mr. C. W. Darley	700	1,250
Hastings	Mr. C. W. Darley	650	2,133
Camden Haven	Mr. C. W. Darley	400[1]	2,413
Manning	Sir John Coode	800	2,267
Port Forster	Mr. C. W. Darley	400	7,313
Newcastle Harbour	Mr. E. O. Moriarty and Mr. C. W. Darley	1,200[2]	3,426
Lake Macquarie	Mr. E. O. Moriarty	1,300[3]	9,300
Crookhaven	Mr. T. W. Keele	600[4]	3,110
Moruya	Mr. E. O. Moriarty	950[5]	1,620

[1] Curved northern breakwater added by Mr. T. W. Keele.

[2] Entrance diverges slightly seaward : minimum width, 1,200 feet ; maximum, 1,450 feet.

[3] Reduction to 200 feet recommended by Sir John Coode.

[4] Widened to 1,300 feet by Mr. E. M. de Burgh.

[5] Inside work (training-wall) proposed by Mr. Darley, practically reduces the width to 550 feet.

Camden Haven was a small inlet having at its back some lakes of considerable area, in which there was only a few inches of tidal range. Cape Hawke harbour (or Port Forster) was somewhat similar. The entrance to Lake Macquarie was by a narrow channel about 3½ miles long, extending from the ocean to the lake, which had a water-area of 27,900 acres, and was practically tideless. Bateman's Bay was quite different from all of these, being about 5 miles wide at the coast-line, and narrowing to about 900 feet 5 miles back from the coast, where it received the waters of the Clyde River. The bay had a rocky shore on both sides. Wagonga was an inlet of the sea, carrying water 40 feet to 50 feet deep over the larger portion of its area, and was generally similar on a small scale to Sydney Harbour, having a rocky coast on both sides of the entrance. The Manning had two entrances, one at Harrington and the other at Farquhar, 7 sea-miles distant, both of which admitted large quantities of tidal water and allowed of the discharge of flood-

Mr. Rossbach. waters. Crookhaven, with a drainage-area of only 40 square miles, was connected with the Shoalhaven (drainage-area about 2,761 square miles) by what was known locally as "The Canal," which carried a large portion of the Shoalhaven waters to and from the Crookhaven entrance. The Bellinger, Macleay (new entrance) and Manning rivers had no rocky headland on either side, but only sandy beaches, extending in some cases for several miles. The remaining rivers had a headland on one side and a sandy beach on the other. The length of these beaches varied, some of them being many miles in extent. The small places, Tuggarah, Lake Illawarra, Tuross and Bermagui were frequently closed against the sea. It should also be pointed out that the average range of tide in the different tidal compartments varied very considerably, as also did the mean distance of the compartment from the ocean — both matters of great importance. There were also differences in the rainfall, steepness of the catchment-area, nature of the soil, etc., as well as in the extent of the improvement-works carried out. In some cases the works were well advanced; in others, less than half the work proposed had been carried out; while in a few casee no works had been undertaken. Notwithstanding the very varied conditions of these rivers, Mr. Halligan, from a consideration of some of the conditions at three of them, had devised a formula which he would apply to all the rivers on the coast. There was no analogy between Sydney Harbour, Botany Bay and Jervis Bay, on the one hand, and the various rivers on the other. The places mentioned were not rivers, but inlets of the sea; none of their entrances had a sandy beach on one side or the other, but bold precipitous headlands with deep water close up to the shoreline; while they all had a rocky coast ranging in length from $1\frac{3}{4}$ to 8 miles on the one side and from 4 miles to 10 miles on the other. In other words, there was an absence, close to these entrances, of the sand which, as Mr. Halligan said, was "put into suspension by the waves, and slowly moving with the current along the beach, at length reaches an inlet, and is carried into the estuary by the flood-tide." The beaches in these cases were miles away. As far as observations went, the larger portion of the littoral drift on this coast occurred over a strip extending from high-water mark to 2 or 3 fathoms below low water; but if any sand got into the three places named, it must be at depths of 60, 90 and 120 feet below low water, where there was no wave-action such as that which placed sand in suspension on the beaches. Again, the three tidal compartments referred to had each a tidal range equal to that of the ocean outside, whereas in the case of every river mentioned by Mr. Halligan the range was only about one-half of that

Mr. Rossbach.

outside. For instance, the Clarence River, which had the largest tidal compartment, though subject to tidal influence over about 68 miles of its length, had a range at its mouth of about 5 feet at spring-tides, and at 20 miles up-stream only about 1 foot 6 inches. The Hunter River had 5½ feet at the entrance, and at Maitland, about 40 miles up-stream, only 2¼ feet. In some cases, such as at Camden Haven and Port Forster, the average range was probably much less than in the typical cases mentioned, owing to a large portion of what was called "tidal compartment" consisting of lakes wherein the tidal range was only a few inches. Many of the tidal compartments were also incapable of being completely filled and emptied by tidal water, no matter what the entrance-width might be. It was obvious that a formula based on a full range of tide in the tidal compartment could not apply to a compartment where the possible range was only one-half or less. That the factor was not the area of the tidal compartment but its capacity for tidal water would be clear when the areas of tidal compartments of those rivers having somewhat similar conditions were placed in order of their size, and their depths were compared. It would be found that they fell into practically the same order, namely:—

Rivers at which breakwaters had been built on both sides of the entrance—

	Tidal Compartment (Approximate only). Acres.	Depth on Bar at L.W.S.T. Feet.	Inches.
Hunter (Newcastle)	10,280	22	0
Richmond	6,800	10	3
Moruya	1,620	7	2

Rivers at which no breakwaters had been built, or only on one side, and that the rocky side—

	Tidal Compartment (Approximate only). Acres.	Depth on Bar at L.W.S.T. Feet.	Inches.
Clarence	34,000	11	4
Crookhaven and Shoalhaven	9,330	11	3
Macleay	6,800	7	10
Hastings	6,400	6	6
Tweed	5,000	6	5
Clyde (Bateman's Bay)	4,253	5	10
Manning	3,750	7	4
Nambucca	2,730	5	4
Bellinger	1,640	5	5

Rivers which had tidal compartments consisting largely of lake areas—

	Tidal Compartment (Approximate only). Acres.	Depth on Bar at L.W.S.T. Feet.	Inches.
Lake Macquarie	27,900	4	3
Cape Hawke	21,938	3	10
Camden Haven	7,240	3	4

Mr. Rossbach. Wagonga Inlet, with an area of 1,600 acres, and a depth of 10 feet 4 inches, stood alone, in that it had an excellent tidal compartment in which the tidal range was more nearly equal to that of the ocean than any river in this list. Mr. Halligan could find only two causes why the three harbours on which he based his formula did not shoal more, namely, the projection of the north headlands and the wide entrances. Mr. Rossbach would suggest a third—that it was mainly due to the heaping-up action of onshore gales producing an under-current seaward, which removed periodically any sand that might find an entrance. The waters of Sydney Harbour were known to have been raised 10 inches above the ordinary tidal level by this means, and it was certain that Port Kembla Bay and other similar bays on the coast had been so cleaned out periodically.

Another conclusion at which Mr. Halligan arrived was that there was no relation between the area of a catchment and the depth on the bar. Mr. Rossbach was of opinion that though the tidal waters were the main factor in determining the depth on the bar, the upland waters were of very considerable value in strengthening the ebb-tide. In the case of the rivers of New South Wales, where there was an absence of wide estuaries, where the rivers came abruptly on to the coast, and where the tidal range was small, the upland water was not the insignificant factor that it might be in the case, say, of rivers on the English coast, where the range of tide might be as much as 27 or 28 feet, and the ratio of fresh to tidal water was only 1 to 250, 1 to 300 or even 1 to 1,500. For instance, taking the case of the Hunter River—with a catchment-area of 8,269 square miles, an average annual rainfall of 36 inches, and a tidal compartment of 10,280 acres, with an average range of 3 feet 6 inches—and assuming the low figure of 30 per cent. for discharge, the average quantity of upland water discharged per annum would be equal to between one-fourth and one-fifth of the quantity of tidal water entering the river in the year. A large portion of this upland water was discharged in freshets and occasional floods, when it scoured out sand that had accumulated during periods of small flow; but there was always more or less water coming down the river which, ponded up during the flood-tide, was discharged on the ebb. This was thereby more or less prolonged, and he considered this extension of the period of the ebb to be a factor of some importance in maintaining the depth over the bar in the case of New South Wales rivers. Mr. Halligan pointed out that only the same quantity of tidal water passed out of a river as previously entered; that the velocities which he had measured on the ebb and flood at any one place were equal; and that the flood-tide was assisted by the waves in bringing sand into the entrance: but as there were no waves to disturb the sand on the

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ebb, the inference to be drawn was that the upward forces through the entrance were greater than the downward. It was obvious, however, that there must be some equal force or forces to carry the sand out again, otherwise these rivers would ages ago have ceased to exist. As an instance of the enormous quantity of sand which was sometimes scoured out by upland water in time of flood, the Clarence River might be mentioned. Here, in the flood of 1887, the unprotected portion of the northern spit was swept entirely away, leaving 33 feet where previously the spit had been dry at low water; and 32 to 40 feet on the bar, where previously there had been about 12 feet. It was difficult, therefore, to see no relation between the area of the catchment and the depth on the bar. It was interesting to note that while the tidal water was the main factor in maintaining the depth on the bar, the relation of the catchment-area to the depth was also well marked when the catchment-areas were placed in order of their size:—

Rivers at which breakwaters had been built on both sides—

	Catchment-Area. Square Miles.	Depth on Bar at L.W.S.T. Feet.	Inches.
Hunter	8,269	22	0
Richmond	2,683	10	3
Moruya	609	7	2
Lake Macquarie	291	4	3

Rivers at which no breakwaters had been built, or only on one side, and that the rocky side—

	Catchment-Area. Square Miles.	Depth on Bar at L.W.S.T. Feet.	Inches.
Clarence	8,505	11	4
Macleay	4,581	7	10
Manning	3,164	7	4
Crookhaven and Shoalhaven	2,801	11	3
Hastings	1,389	6	6
Bateman's Bay	696	5	10
Nambucca	552	5	4
Cape Hawke Harbour	514	3	10
Bellinger[1]	479	5	5
Tweed[1]	418	6	5
Camden Haven	238	3	4

When it was remembered that large lake areas existed at Lake Macquarie, Cape Hawke, and Camden Haven, which acted as balance-reservoirs and retarded the flow of the upland water, it appeared more than a coincidence that the depths on the bars fell into place so well. In order to prove that there was no relation

[1] Breakwater works further advanced than in the case of Nambucca.

Mr. Rossbach. between the catchment-area and the depth on the bar, Mr. Halligan instanced the Clarence River, with 8,505 square miles, and Crookhaven, with only 40 square miles, having equal depth; also the Richmond, with 2,683 square miles, having the same depth as Wagonga, with only 52 square miles. With regard to the first comparison, it had already been explained that the Crookhaven carried, in addition to its own waters, a large portion—and sometimes the whole—of the Shoalhaven. The explanation of the second case was that at Wagonga, with its excellent tidal compartment, the value of the tidal water far outweighed that of the upland water. This tidal compartment was very spacious, was close to the ocean, had a large tidal range—at spring-tides 4 feet 6 inches at the entrance and 3 feet 6 inches at its extreme distance from the ocean—and was rapidly filled and emptied each tide. It was certain that, compared with other rivers having similar areas of tidal compartment, much more tidal water flowed into Wagonga; hence the better scour. In passing, the inference that might be drawn that the Clarence River entrance, after having had £466,000 spent on it, was to be regarded as a failure, should be corrected. Of the amount mentioned, £182,830 had been spent on a scheme subsequently abandoned in favour of one proposed by the late Sir John Coode, the expenditure on which had been £283,419. The first work recommended by Sir John Coode was the building of the first sections of the breakwaters, the inside training-walls to follow. On the recommendation of a non-professional Parliamentary Committee, however, all the internal works had been constructed, but the outer or breakwater works, which, if built, might have been expected to improve the bar and prevent the ingress of sand, still remained untouched, as did also the removal of the rocky patch in the entrance, which Sir John Coode proposed to remove to a depth of 18 feet at low water. Had the works been carried out in the order recommended, the results their designer anticipated would, in Mr. Rossbach's opinion, have been fully realized. Mr. Halligan considered that the only effect of £422,000 spent on the harbour scheme at the Richmond River had been to fix the bar, which formerly wandered about over 5,000 feet of coast. He overlooked or had forgotten, however, the difficulties and dangers encountered by vessels before these works were commenced; also the fact that, as the improvements progressed, the shipping-companies increased the size of their vessels, that these now entered practically at all times, and that they were seldom delayed except by bad weather. Sir John Coode had anticipated a depth of 12 feet at low water, and for many months together the depth ranged from 10 to 15 feet, though the scheme had not yet been completed, and there had been an almost entire absence of flood conditions for 17 or 18 years. The sandbank referred to as encroaching on the channel was due to a combination of causes. It lay on the convex side of the river, where there would be a natural tendency to shoal; also, large quantities of sand were blown over the breakwater during the prevalence of southerly winds, and were trapped on the shoal ground, over which the velocity of the tide was very low and not sufficient to move the sand under ordinary conditions. This Mr. Halligan was now endeavouring to stop by the planting of marram-grass and other vegetation. Again, it was stated that the sand was fast filling the estuary. This was not correct: as the training-works progressed, the sand which had accumulated in the estuary moved downstream, as shown by periodical soundings. A large portion of the sand-spit shown in Fig. 7, Plate 5, had disappeared, and the recent reports stated that the river-entrance was in better condition than ever before. True, owing to recent heavy weather the entrance had shoaled to 8 feet, and assistance was now being rendered by dredging; but this was only temporary and was liable to happen no matter of what width the entrance might be. The remark about a large amount of dredging having been carried out, both at the Richmond River and at Newcastle, without any resulting increase in depth on the bar, was misleading. The larger portion of the dredging at the Richmond River during recent years had been done not for the purpose of deepening the bar, but for widening the channel at the upper end of the sandbank shown on the plan, where there was a very sharp turn, difficult to navigate. At Newcastle the dredging was not at the point where the least depth was reported by the pilot (this being rocky and not capable of being dredged), but to the north of the fairway-line, where there was now better water than previously, as the result of dredging. This explained how it was that, as Mr. Halligan said (p. 146), no improvement was reported in the depth at either place at the end of the period. Mr. Rossbach.

The views expressed as to the effect on the ocean-current of the various-shaped headlands, in Mr. Rossbach's opinion, needed to be supported by many more observations than had been made before they could be fully accepted. An inspection of the coast-charts showed no headland concave to the north which would cause the counter-current said to set to the north past the Richmond River entrance; nor did it appear probable that Crowdy Head caused a set to the north past Harrington and Farquhar Inlets, $3\frac{1}{2}$ and $10\frac{1}{2}$ sea-miles distant respectively from the head. Other similar cases might be

Mr. Rossbach. mentioned. It was also difficult to see how, if the north-east wind increased the velocity of the counter-currents, the southerly winds should also accelerate them, as stated by Mr. Halligan. With regard to littoral drift, his own observations had led him to the conclusion that the greater part of the sand moved over the space between high-water mark and the 12- or 18-feet contour-line below low water. The sand was put into suspension by the waves and carried by the alongshore current, which might be accelerated, retarded, or reversed by the winds, according to their direction and force. Strong winds in some places caused the waves to break with a certain amount of obliquity on the shore; this also moved the sand in the direction of the wind. The velocities of the currents measured close alongshore, where most of the drift took place, were very low (generally about $\frac{1}{4}$ knot per hour or less), and they were easily reversed by the wind; consequently, notwithstanding that the ocean-current ran to the south, large quantities of sand could be moved to the north by the southerly gales, which were much more numerous than those from the north. He thought Mr. Halligan undervalued very much the effect of the southerly gales on the movement of sand; in some cases it could only be described as enormous. He had seen the southern end of a beach denuded of sand by a south-easterly gale to such an extent that, during 8 to 9 months of normal weather afterwards it was not made up again to its previous condition. On the coast of New South Wales, where the prevailing wind came from the north-east, not only did the river-entrances at the southern end of beaches shoal, as stated by Mr. Halligan, but those at the northern end shoaled also. The position as regarded sand-movement on the coast appeared to be a struggle between the ocean-current acting almost continuously from the north and carrying sand in comparatively small quantities, and occasional heavy gales from the south during which the sand was disturbed to a much greater depth, and carried in very large quantities to the north. Whether the ultimate movement of the sand was from north to south, or the reverse, there was not sufficient evidence at present to show.

Mr. Halligan considered that the width of entrance should be so determined that the velocity of the ocean-current should be greater than the flood-tide between the ends of the breakwaters, in which case the sand would be carried past in the stronger stream and would be harmless: and he stated that if this condition could be obtained, all dredging within the estuary became a permanent improvement. With the low-velocity coastal current, as measured off a number of the river-mouths, it would appear to be impossible to do this without making the entrance so wide that the most permanent thing would be the dredging. The tidal compartment had to be filled with water from the ocean; and if such water carried sand put into suspension by the waves, some sand must necessarily pass into the entrance, whether by a low- or a high-velocity current. The low-velocity flood-current due to an excessively wide entrance would admit of the precipitation of the sand close to the river-mouth. On the ebb-tide, however, the precipitated sand would not be disturbed to the same extent by the waves, and this low-velocity current would be powerless to move it seaward: hence an accumulation, which would require very frequent dredging to maintain a navigable channel through it. While Mr. Rossbach—who held the position of Principal Assistant Engineer in the Harbours and Rivers Branch of the Public Works Department, and who had had 34 years' experience in connection with harbour-works and for about 23 years had done all the designing of the works described by Mr. Halligan, under the various Chief Engineers—held views at variance with Mr. Halligan on some points, he desired to express his appreciation of the effort made to throw light on one of the most difficult problems in engineering. Mr. Rossbach.

Mr. W. H. Shields was much interested by Mr. Palmer's Paper on Fremantle Harbour, which although brief contained so much information that little remained to be added, except concerning the various graving-dock proposals. He thought, however, that the author would be interested to know that since he severed his connection with the Department and State which he had graced as Engineer-in-Chief, the two small patches of silting had practically disappeared, the whole harbour showing signs of scouring out. There were now few places with less than 33 feet at low water (phenomenal low water, only once known). Were it not for the large quantity of stone thrown in to protect the railway-bridges from scour, probably the whole of the river, with the exception of the rocky bar, would scour out to 40 feet or deeper between the entrance and Melville Water. The two small patches of silting were generally supposed to be due to eddies formed by the filling originally left below the mail-boat jetty. The electric cranes had proved highly successful in working. Mr. Shields.

Mr. Voisin, of Boulogne-sur-Mer, remarked that the history of the development of the approach to the Newcastle Harbour possessed the greater interest because it so rarely happened that engineers were entrusted with the carrying out of like work where research could furnish such useful information and such valuable instruction. Generally speaking, Mr. King showed that the state Mr. Voisin.

Mr. Voisin. of affairs, which was risky and even dangerous in 1816, had been made, if not perfect, at all events entirely satisfactory, by the combined influence of structural works and increasingly extensive dredging; and he pointed out that the proposed new extensions, coupled with suitable dredging, rendered it probable that the results hoped for—namely, a channel with a depth of 30 feet at low water and a reasonably safe approach in all weathers—would be achieved. Mr. Voisin concurred in this hope, as being in conformity with the accepted data upon the subject. It would indeed be difficult to claim that a similar result could be obtained exclusively from the construction of piers by making the opening between them more or less equal to that suggested by Mr. Halligan, which in this case would be 2,570 feet in place of 1,200. It seemed desirable, in Mr. Voisin's opinion, to draw attention to a want of concurrence in the two Papers, the wetted area being given in Mr. King's Paper as 6,500 acres, and in Mr. Halligan's Paper as 10,280 acres, while the width between the breakwaters, according to the former (scaled from the plan), was in 1907 about 1,450 feet, as against 1,200 feet given in the latter. It was noticeable that the distance between the heads, a distance which Mr. Halligan regarded as a basis of design, had been gradually reduced from 2,750 feet in 1903 to 2,000 in 1907, while the effect of the new works proposed would be to reduce it to 1,900; but that, notwithstanding this, the position, instead of being made worse, had been very appreciably improved, thanks, in a measure, to dredging. Mr. King gave the current during floods as having a velocity of $7\frac{1}{2}$ knots per hour, and, during the ebb, 2·6 to 1·7 knots (Chart of 1909), in place of the 3·3 knots stated in Mr. Halligan's Paper. This velocity had diminished progressively, and would doubtless continue to do so. Could it be said that the extension of the north breakwater would stop for an indefinite time the invasion of the channel by sand coming from Stockton Bight? Mr. Voisin did not think so, and he agreed with Mr. Halligan that the effect would be only temporary, and that it would without doubt be necessary to resort to further extension, until a point was reached where the depth of water was sufficient to prevent further sea-action on the sand—a point which would be reached the sooner by reason of the low velocity of the littoral current. However, the fact must not be lost sight of that dredging would permit any given state of affairs to be maintained during a longer or shorter period, according to the extent to which it was employed—an extent which would appear to be somewhat large owing to the considerable movement of the sand concerned, but which was amply justified by the magnitude of the interests involved, and especially by the economic development of Newcastle. The colossal work carried out with success in the Mersey Bay showed what could be done in a proportionate way at the mouth of the Hunter River. Mr. Voisin.

Too much stress could not be laid on the remark made by Mr. Halligan at the beginning of his Paper, that each harbour constituted a special case, and it was thus necessary, in designing any works, to apply the general principles after having thoroughly grasped the local circumstances. It was one of these general principles which Mr. Halligan endeavoured to establish for the comparatively simple case where no tidal current—at any rate parallel to the shore—existed, and the littoral current (ocean-current) ran in a constant direction. As stated in the Paper, it was more usual for the littoral current to be absent, or if present to be ill-defined, while it was the tidal current setting along the shore which predominated and undoubtedly caused complications in the problem. It seemed possible, in passing, to sum up the principles laid down more or less broadly by different engineers (Messrs. Coode, Haupt, and others), by observing that the movement of sand was the result of a variety of forces—currents of all kinds (littoral, tidal, or fresh-water), winds, etc.; and naturally the larger the number of these acting forces the more intricate was the examination of the phenomena: and thus in the special case of the New South Wales coast where there was neither an alongshore current nor any appreciable upland water, it had seemed possible to Mr. Halligan to formulate a law, the accuracy of which it would be interesting to test in other similar situations. It was according to the general law indicated above that in cases similar to that on the New Jersey coast the movement of sand was dependent much more upon the tidal and littoral currents than upon the wind, the mean effect of which did not always coincide with the tidal current, although very often it assumed the direction of the flood. Mr. Halligan analysed what had taken place at the entrance to one of the estuaries in New South Wales. The observations appeared reasonable, but possibly it was undesirable to adhere too closely to these deductions, which were dependent upon a determination to avoid sanding up—a determination which was certainly reasonable, but which should not be considered to the exclusion of others which might be of even more importance: for frequently, even in the case of Newcastle Harbour, at the mouth of the Hunter River, it was neither very difficult nor very costly to successfully combat the accumulation of sand. Thus, Mr. Halligan recommended that the breakwater which opposed directly the littoral current should be

Mr. Voisin. lengthened beyond the other, and it might easily happen in certain cases that a like arrangement could be avoided, for the convenience of navigation, only by having recourse to a little dredging. In the same way he recognized with justice that, in order to obtain greater stillness in the harbour, it might be necessary to reduce the entrance-width below the limit which he indicated. He pointed out that the width at the entrance which he contemplated was the distance between the ends of the breakwaters, and not necessarily the shorter distance across the entrance. It seemed difficult, however, especially if the line joining the heads was very oblique to the centre-line of the channel, as, for instance, in the design proposed by him for the improvement of the entrance to the Richmond River, to admit that the width measured upon this line would indicate the same as that measured at right angles to the centre-line of the channel. Besides, in the three examples which had served to illustrate the proposition, the two lines were practically coincident, a fact that did not warrant the assumption that these two widths were equivalent. Mr. Voisin would like to add

(1) That the formula brought forward for the width of an entrance, namely, 1 foot per 4 acres, was applicable only to large estuaries like those cited; for such as were of less importance it would involve widths very much too small, so that, when considering areas of less than 1,000 or 1,200 acres, the exigencies of navigation must be the sole guide.

(2) That the formula itself seemed capable of application only with the greatest reserve, as it ignored a number of important factors, such as the duration of the tide, the section of the channel, etc. It also seemed inadmissible to assume that the flood-tide should have a greater velocity than the littoral current in order to bring into the estuary only a slight deposit. Further, a roughly approximate calculation seemed to show that the proportion of 1 foot to 4 acres was rather on the small side than otherwise. However, Mr. Voisin thought that conclusions such as those laid down by Mr. Halligan, when relieved of numerical significance, were of considerable interest.

With regard to the Paper by Mr. Palmer, in the absence of plans of the harbours of Albany and Banbury, it was difficult to form any definite opinion upon the very brief description of those works, but the general situation on the west and south coasts of Australia presented some similarity with that on the east coast. Thus, it was noticeable that a regular current existed, almost constant in direction (except during gales from the north-west, which appeared to be infrequent) and somewhat similar to that on the east coast, but Mr. Voisin. Mr. Palmer made no mention of the direction taken by any tidal currents in the open sea. It would have been interesting to know if, as on the coast of New South Wales, these approached at right angles to the shore-line, and were thus without any appreciable influence on the nature of the bed in the open sea or in the estuaries. No doubt this lack of precision was due to the insufficiency of the observations made on this great length of coast; but failing further information on this head, it would be interesting to know whether the relation found by Mr. Halligan to exist, between the width at the mouth of an estuary and the wetted area of such estuary, obtained on the western and southern coasts of Australia, as well as upon the eastern, since it seemed that in the former also the action of the land water might be considered as of small importance. As regarded Fremantle Harbour, it was easily realized that the engineers were concerned on account of the sand-movement at its entrance, especially at a time when the manufacture of dredging-plant was in its infancy. It was also apparent that these fears must have been the more real because at that time the financial resources of the Colony were of the smallest, and it was difficult to estimate what the future held in store. The history of the design and execution of the works at Fremantle, as related by Mr. Palmer, placed also in evidence the hesitancy and mistakes to which the incomplete knowledge of the situation had led; but in a new country, as Western Australia then was, perhaps it was better to run a risk than, by hesitating, to entail a delay in the economic development of the country; and boldness was doubtless more to be desired than extreme prudence. The solution eventually adopted seemed certainly the best, for it was preferable to locate the new berthage immediately within the mouth of the Swan River and in the town itself, rather than at a distance as proposed by Sir John Coode. As Mr. Palmer did not give the weight of the large stones tipped on the outer slopes of the breakwaters, especially of the north one, it was impossible to criticize the section adopted. However, on referring to Figs. 6, Plate 7, and to the description in the text, it was evident that even during the north-westerly gales the sea was not heavy, a state of affairs which might to some extent be expected from the lie of Fremantle. The somewhat crude system employed in executing the rock facing under the quays could not give entirely satisfactory results, even when the material was as suitable as that at Fremantle, but it was evident that the settlement stated to have taken place, especially at the south quay, had not been attended with any serious consequences. Some more detailed account of the jarrah timber

Mr. Voisin. employed in the construction of the quays would not have been without interest, though already it was known that Australian jarrah was eminently capable of withstanding the attack of the teredo and of marine worms. Fig, 9, Plate 7, did not show how the electric cranes would be installed, as on the quay-side two railway-tracks only were shown and no crane-road: it must, however, be assumed that the width of the quay was sufficient for the cranes to be placed astride the other tracks. An extremely interesting point was the wind-screen placed along the shore, immediately behind the north quay; but from its construction, as described in the Paper, it seemed again to be clearly indicated that the sea was not very heavy at this point. With regard to the arrangement of light-sectors at Woodman's Point, it was curious to note that red faced the shallower navigation while green was used to mark the dangers; it would have been more in conformity with tradition if the reverse had obtained. It was to be regretted that the cost of dredging by bucket dredgers had not been given, as had been done in the case of sand-pumps, where the figure was almost as high as might be expected for good bucket dredgers. In conclusion, it was interesting to note the success of the works undertaken at Fremantle, a success which did credit to the engineers responsible for their design and for their subsequent construction.

Mr. Walmisley. Mr. A. T. WALMISLEY thought that, while Mr. Halligan emphasized the importance of adequate width of entrance, he appeared to overlook the value of depth, which was a controlling element in the discharge of a channel. In considering a wide entrance it must be remembered that, when the water within the entrance became slack, it deposited any sediment held in suspension; unless, therefore, a scour was created to maintain a tidal channel of ample capacity for the requirements of the harbour, the cost of dredging became a constant item. Experience alone would enable the harbour-engineer to decide the mean between the advantages of a width sufficiently narrow to maintain scour and sufficiently wide to provide facility of entrance at all states of the tide.

Mr. Walsh. Mr. H. D. WALSH, having been Government Engineer in charge of the Newcastle harbour-works for a number of years previous to 1901, was much interested in Mr. King's Paper. During the earlier stages, from 1866 to 1880, owing to want of funds, the works were carried on in a very intermittent way; but even between these dates a gradual improvement was noticeable in the entrance, as a result of the training-walls constructed. The chart of 1866 showed a 21-foot channel only 150 feet wide, while that of 1907 showed a much straighter entrance; the 21-foot channel had widened out to 450 feet, and the sand spit near the end of the north breakwater was "slowly but surely disappearing." As no dredging had been done at the entrance before 1908, these improved conditions must have been the result of the construction of the breakwater. It was often found during the construction of works at river- and harbour-entrances that, owing to gradual alteration of natural conditions, the entrance for navigation purposes was, for a time, even worse than before the works were started. In the case of Newcastle, which was probably the most difficult harbour on the coast of New South Wales to deal with, the improvements, although considerable, had not been so great as might have been anticipated from such extensive works; but Mr. Walsh had no doubt as to the ultimate successful results of the breakwaters as constructed. One of the factors relied upon for the improvement of this entrance was the great scour caused during flood-time, which it was anticipated would scour out the large accumulation of sand that had encroached from the northern side while the works were in progress. In order to show that it was reasonable to rely upon this assistance, it might be mentioned that between the years 1868 and 1898 there were eleven floods in the Hunter River which rose above 30 feet in the gauge at Belmore Bridge, West Maitland; but no such flood had occurred since the north breakwater was sufficiently far advanced to render such scour effective. During the flood of 1893, when the river rose to 37 feet at Maitland, there was a continual flow out of the entrance at 4 to 6 knots per hour for 4 days, the tide-gauge showing a difference of 10 inches to 2 feet between high- and low-water marks. He was confident that, were such a flood to occur now, the whole of the accumulations of sand would be carried out to the coastal current and dispersed, thus nearly doubling the sectional area of the channel between the breakwaters; and as the inflow of sand from the Oyster Bank would be cut off, there seemed no reason to anticipate that the ebb-tide would not be sufficient to maintain the entrance. Considerable difficulty had been experienced during the construction of the first 2,000 feet of the north breakwater, owing to the inrush of beach-sand and the excessive scour at the tip-head; and the sea on the Oyster Bank being very treacherous, it was thought inadvisable to blanket with rubble stone from punts. In 1903 the scour had increased to such an extent as to maintain a channel about 36 feet deep around the tip-head, and the large quantities of sand entering the harbour threatened to interfere seriously with navigation. It was with the object of Mr. Walsh.

Mr. Walsh. arresting this scour at the tip-head and forming a temporary breakwater to keep out the sand encroaching from Stockton Beach that he suggested blanketing the bottom in the line of the breakwater with hulks, as described by Mr. King. The novel suggestion was submitted to an advisory board of engineers, which, having approved the scheme, requested him to superintend the placing of the hulks in position. This he did with the assistance of Mr. King, and, as stated in the Paper, these somewhat hazardous operations were carried out without mishap of any kind. The work proved a complete success, and by reducing the depth at the tip-head enabled the breakwater to be extended at the rate of 80 to 100 feet per month as against 10 feet per month previously. The saving was about £30,000.

With regard to Mr. Halligan's Paper, he thought that all engineers dealing with marine works on the coast of New South Wales would feel indebted to its author for the valuable information he had supplied in connection with the various winds and currents, even though they might not be able to accept the formula he had evolved for their use in designing harbour-works in the future. It would be interesting to know why Mr. Halligan had dealt only with the width of the entrance. Taking, for instance, the case of Jervis Bay, with an entrance 11,590 feet wide and 120 feet deep, the tidal compartment was given as 28,326 acres, and, taking the rise of tide at 5 feet, 6,170 million cubic feet of water passed through the entrance in 6 hours, with a velocity of $\frac{1}{2}$ knot per hour. Did Mr. Halligan contend that this body of water could pass through the entrance if it were only 20 feet deep (instead of 120) without increasing the velocity? If not, surely the sectional area, and not the width alone, must be considered, in order to carry out his theory of keeping the velocity of the flood-tide below that of the coastal current. Mr. Walsh was aware some scientists held that only the upper layers of water need be considered in dealing with a flood-tide entering a river or estuary, but having had considerable experience with divers working at harbour-entrances, he was convinced that the current was at least as strong within a few feet of the bottom as at the surface. At Newcastle entrance, divers were only able to work at slack water on the bottom in 30 to 40 feet of water; immediately the tide began to flow the men were carried off their feet and had to be hauled on board the attendant vessels by their life-lines. It was scarcely necessary to add that only the bottom layers of current carried sea-sand to any extent. If the sectional area of an entrance, and not its width alone, were considered, it was interesting to see how Mr. Halligan's theory with regard to the velocity of the flood-tide worked out. At Newcastle the sectional area between the breakwaters 300 feet north-east of Stony Point was 22,800 square feet, Mr. Walsh. and the flood-tide velocity, as shown by Mr. King (Fig. 10, Plate 6), was 2·6 knots per hour. If, as anticipated, the channel scoured out to its full depth, the sectional area would be increased to about 52,000 square feet, in which case the flood-tide, which now entered at 2·6 knots, would enter at 1½ knot, or less than the velocity of the coastal current off the port. Further, seeing that the wharves were situated immediately inside the entrance, the existing entrance provided better protection for vessels berthed at them than would be the case if the entrance, which was exposed to heavy easterly seas, were made 2,570 feet wide, which would be necessary if Mr. Halligan's formula were adopted. In considering the relative velocities of the ebb- and flood-tides outside an entrance, it must be remembered that the flood-tide did not travel in a direct line from the ocean-current, but entered in a fan shape from all points round the entrance, and therefore the velocity was not so great a short distance out as when well inside the breakwaters. It would be noticed that in Mr. King's chart of 1909 the flood-velocity between the 7-fathom and 8-fathom lines off the south breakwater was shown as 0·5 knot per hour, although it increased to 2·6 knots farther in. On the other hand, the ebb-tide passing out in a direct line between the breakwaters continued in that line until turned by outside influences. In the case of Newcastle, observations showed that the ebb-tide influence was felt for a distance of 800 feet beyond the end of the breakwaters. It would be interesting to hear Mr. Halligan's experience on this point. In the case, say, of the Hunter River, it was somewhat difficult to realize the truth of the statement that upland waters might be disregarded altogether as having no effect on the harbour-entrance. With a watershed-area of 8,269 square miles, and an annual rainfall of 36 inches, it did not seem probable that the discharge from this river gave no assistance whatever to the ebb-tide. Most engineers would no doubt agree with Mr. Halligan's concluding remarks that if his theories were accepted, the future work of marine engineering on the coast of New South Wales would be very simple. He had given, in his Paper, particulars of the coastal current; it would only be necessary, therefore, to send a surveyor and measure the width of the entrance and the area of the tidal compartment. The engineer could then decide whether to increase the width of the entrance and obtain the required 1 foot to 4 acres, or to reduce the tidal compartment, by reclamation or other means, so as to obtain the same proportion.

Mr. Wheeler. Mr. W. H. WHEELER found a great deal to be learned from the three Papers under consideration. Mr. Halligan stated, as the result of his experience and observations on the eastern coast of Australia, that the movement of the littoral drift, composed almost entirely of sand, was due to tidal action alone and not to the wind. Although this was contrary to the opinion generally accepted as to the movement of drift-material on sea-beaches, it agreed with the facts brought forward in Mr. Wheeler's Paper on Littoral Drift read at the Institution in 1896.[1] The theory as to this movement which was there set out had been proved to be correct by further experience. In not a single case had he been able to find that the regular and continuous movement of littoral drift was due to the action of the wind. It was generally admitted that the effect of onshore gales on beaches was to tear out the shingle and lower the surface of the beach, and that in calm weather or offshore winds the material so pulled down gradually drifted back again and the beach was restored. Recently he had an opportunity of watching the action of the drift along the shore on the east coast under very favourable conditions. A quantity of ballast for road-construction had been discharged from barges into carts at about half-tide level, and some of it had fallen on the beach. This material was different in character and colour from that which composed the covering of the beach, so that its movement could be traced. At every tide some portion was carried upward and forward along the beach in the direction the flood-tide was taking; and pieces as large as half-bricks were moved in one tide 25 yards upward and 70 yards forward. In the course of a few days pieces of this ballast were to be found at a considerable distance from the place where they had been deposited. The tides were about half-spring, the wind was light, and what there was of it was offshore. It was therefore evident that the movement of this ballast could not be due to wind-action. Another point to which Mr. Halligan drew attention was that along a coast where a littoral drift of sand occurred, and at the same time the shore on the side from which the drift moved extended out from the land on the other side at the entrance to a tidal river, the river-entrance was not encumbered by a sand-bar. Examples of this were cited in Jervis Bay, Botany Bay, and Sydney Harbour. Attention was drawn to the

[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.

same fact in a Paper[1] Mr. Wheeler presented to The Institution in 1890, and illustrations of bar-less rivers in England were given there. The lesson taught by Nature did not, however, appear to have been taken advantage of in the works that had been carried out for the improvement of the harbours in Australia. Thus, at Newcastle the south breakwater had been carried out far in advance of the north, and with the flood-tide and the sand drifting along the coast coming from the north, it formed a trap to catch the drifting sand. The result, as stated in Mr. Halligan's Paper and confirmed in Mr. King's, was that enormous quantities of sand were brought into the river-entrance, which had to be dredged out again. Attention was also drawn by Mr. Halligan to the mistake that had been made in contracting the width of the channel unduly where two parallel walls had been constructed, and so throttling the entrance and the scouring action of the tidal water. As an instance of the baneful effect of thus throttling the entrance of the Manning River was cited, where a large bank of sand of marine origin had been formed inside the two training-walls. Taking generally the works that had been carried out for the improvement of the river-entrances described in Mr. Halligan's Paper and shown in the illustrations, in the case of the Richmond River the net result of £420,000 expended had only been to fix the position of the bar in one place; and, as the Author observed, something more might have been expected from the expenditure of so large a sum. In spite of constant dredging, no improvement in the depth of water had been obtained. In view of the inefficient results achieved here and elsewhere, in comparison with the money spent, the question arose whether as good or better results would not have been obtained at less cost by constructing a single wall, as suggested in Mr. Wheeler's Paper on Bars, already referred to, this wall to be placed on the side of the channel from which the littoral drift came, and be carried out into deep water beyond the influence of the littoral drift. The concave side being next the river-channel, the single wall would act as a groyne, stopping the littoral drift from entering the river-channel; the ebb-current from the river and estuary would follow the concave side, while the tidal water entering the river-channel would not be throttled. A good natural example of a connection of a river-channel with the sea carried out on these lines was to be found in the entrance to the River Humber. There a natural breakwater of shingle extended out

Mr. Wheeler.

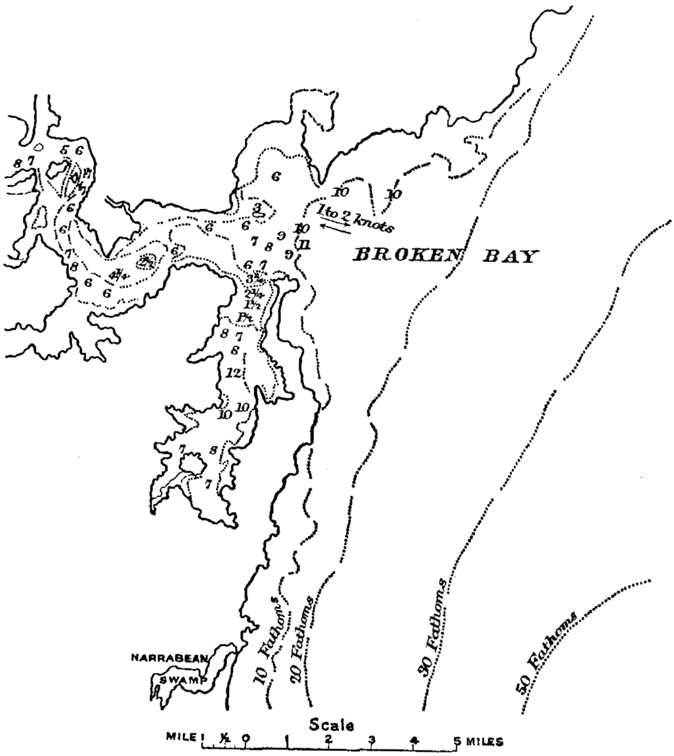
[1] "Bars at the Mouths of Tidal Estuaries," Minutes of Proceedings Inst. C.E., vol. c, p. 116.

Mr. Wheeler. to deep water on the north side, from which direction the flood-tide came; it was curved in form and projected beyond the coast-line on the south side. This river-entrance was entirely free from a bar and had water as deep as or deeper than any other part of the channel.

Mr. Williams. Mr. C. J. R. WILLIAMS found that Mr. Halligan had elaborated a theory that lateral movements of sand were due entirely to littoral currents, and that the movements due to wave-motion were of no account, except in so far as the disturbance of the sand enabled the littoral current to get hold of and act upon it. In support of that proposition he stated, among other things, that only on rare occasions did storm-waves reach the shore otherwise than normally to that shore. Mr. Williams's own observations elsewhere did not bear out this statement, and it was not likely to be correct in the face of the figures given in the Paper, showing that the movements of north-east and south-east winds exceeding 20 miles per hour in velocity were as 47·4 to 57·9. At Nelson, near the head of Tasman Bay, in the South Island of New Zealand, where Mr. Williams advised on, and for a time superintended the cutting of, a new entrance to the harbour, the harbour was protected by a boulder bank composed of hard stones 6 inches to 12 inches in diameter, which extended for 5½ miles from a rocky bluff, the source of supply. The broken stones found on the beach were quite angular at the bluff, but showed a gradual rounding effect as they receded from the source of supply. Again, at Timaru, on the east coast of the South Island, there were large accumulations of shingle against the projecting south-east breakwater, and before the extension of that breakwater the shingle, ¾ inch to 2 inches in diameter, used to be carried into and across the entrance of the harbour in 21 feet at low water. He would be a bold man who would dispute that this movement was due to the prevailing south-east seas, although such littoral current as passed Timaru was northward. Similar conditions existed at Napier Harbour in Hawke's Bay on the east coast of the North Island. The direction of the breaking waves, of course, would depend to a certain extent on the direction of the winds causing the waves, but it was modified by the contour of the adjacent land. At Sumner, a watering-place immediately north of Banks Peninsula, New Zealand, the direction of the breaking wave was always the same, as south-eastern or eastern seas swung round on the peninsula, and the beach lay normal to the seas, having adjusted itself to this condition, as a beach tended to do at all places and at all times. The diagrams of the action of a current passing a projecting headland (p. 130) did not seem quite correct. With regard to *Fig. 2a*, the effect would be somewhat as sketched, and the counter-current, which undoubtedly existed in most of the bays on the east coast of New South Wales, was no doubt assisted by the eddying action behind the projecting point to the north of each of the bays. This eddying action behind the northern headlands appeared to have been overlooked by Mr. Halligan, and the other diagrams, *Figs. 2b*, *2c*, and *2d*, did not seem to be fair representations of what took place. The current would be diverted outwards, and an eddy would be formed behind the point. This eddying action would in itself account for the counter-current, which, however, might sometimes be assisted by the action illustrated in *Fig. 2a*. *Fig. 2c* seemed to be particularly incorrect, as in such a case the current could not curl round the point and expand itself on the shore as shown: there would be an eddy, with an outward flow immediately behind the headland, and a counter-current for some distance down the coast, independent of any projecting headland to the south. The description of what took place when the littoral current past an estuary exceeded the velocity of the flood-tide current looked plausible at first glance; but even when the speed of the littoral current past the entrance exceeded that of the flood-tide current into the estuary or harbour, the sand must move along the line of the resultant of the two streams, and some of it must enter the harbour whenever there was a current inwards. At Broken Bay, New South Wales (*Fig. 7*, p. 280), the tidal current seemed, on reference to the Admiralty chart, to exceed that of the littoral current, and one might expect, in accordance with Mr. Halligan's theory, to find the entrance blocked with sandbanks; but the actual conditions indicated that the Bay was filling up slowly from within, while the entrance remained deep. On the other hand, there were indications that some sand was actually carried in by the flood-tide current, and was deposited under the shelter of the headland guarding the south arm, and under the first sheltered point in the main arm. It seemed to Mr. Williams more probable that on this part of the coast the littoral current, which was known to have less velocity than that farther north, was carrying very little sand in suspension, and that this was the explanation of the comparatively slight shoaling in the bays here, rather than Mr. Halligan's ingenious theory. A glance at the chart of the coast of New South Wales indicated that the only place where the counter-current could be ascribed solely to the action indicated in *Fig. 2a* was at the Macleay River (*Fig. 8*, p. 281). There the headland protecting Trial Bay from the south-east did actually appear to divert the littoral current, and the pushing of the mouth of the river northward was perhaps traceable directly to that cause. Mr. Halligan referred to the ascertained Mr. Williams.

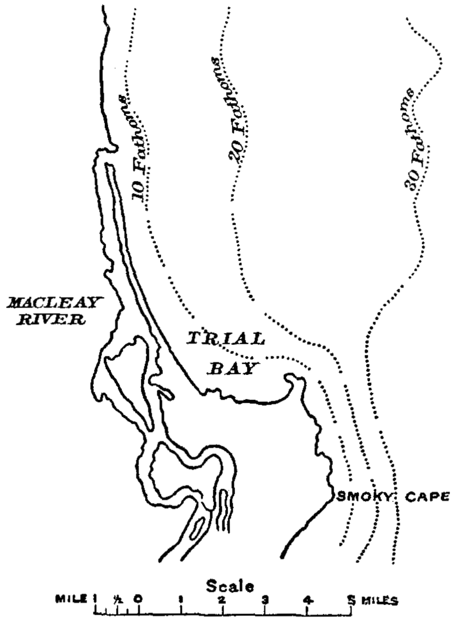
Mr. Williams. fact that during the winter months, when north-easterly weather predominated, the entrances at the southern ends of beaches carried less water than at other seasons. This was exactly what was to be expected, on the assumption that the sand-travel was directly due to the southward component of wave-movement, and appeared to Mr. Williams to tell against the contention that such effects were due entirely to littoral drift. He was in accord to some extent

Fig. 7.



with Mr. Halligan in his pessimistic view of the benefits to be obtained from the ebb-tide current; but the engineer could only use what he had, and it must not be overlooked that, where the tidal rise bore a fair ratio to the depth aimed at, the ebb-current at the period of its maximum strength was flowing through a much more constricted area than the flood-current at the time of its greatest velocity. This might sometimes make the ebb more efficient in scouring than the flood, in spite of the fact that the flood-tide had the assistance of the ocean wave in stirring up the sand; it was especially the case when the outlet was partially sheltered from the seas. With regard to the application of Mr. Halligan's principles to the harbour at Newcastle, there were one or two points in which his statements were not in agreement with those of Mr. King, who stated that during floods the Hunter River brought down large quantities of sand, which were swept out to sea. Mr. Williams's experience in connection with the rivers Mary and Brisbane, in Queensland, was that during floods these rivers brought down large quantities of sand, Mr. Williams.

Fig. 8.



which was deposited in the estuarial compartment. It seemed that there had been some accumulation of sand north of the northern mole at Newcastle, as the shore-line seemed to have advanced about 600 feet since 1866. Finally, one would expect to find, in accordance with Mr. Halligan's theory, a counter-current northward along the Stockton beach; but he showed there a southerly drift of equal velocity to that past the harbour, and seemed to indicate that this was the cause of the sand entering the harbour; while Mr. King attributed it to the flood-tide current. Each case, fortunately for

Mr. Williams. engineers, formed a special study; and while a knowledge of general principles was essential, and sound theorizing on ascertained data was a help to the proper solution of each problem, no precise rules could be laid down. He did not consider, however, that Mr. Halligan had established his main proposition.

Mr. Palmer. Mr. PALMER, in reply, regretted that Mr. Voisin should have thought that settlement of the south wharf was due in any way to the stone facing. The wharf was built on piles, and it was constructed very rapidly, to meet a pressing demand; the piles were sunk by means of the water-jet, and it was owing to their settling that the wharf also settled. Mr. Voisin might perhaps revise his opinion as to the cost of the dredging, when it was pointed out that the wages for ordinary labour were 1*s.* per hour in Western Australia, and all else was more or less correspondingly expensive. Mr. Palmer was indebted to Messrs. Reid Bell, Lefroy, and Shields for kindly placing on record the information regarding the scouring out of the harbour and the washing-down, in a gale, of a portion of the north mole. That the moles would be washed down from time to time had certainly been expected by Mr. Palmer, and also, he was aware, by Mr. O'Connor, who provided very amply in his designs for such washing-down by the sea. Whether what had occurred was more than what was anticipated was not evident from the extract submitted by Mr. Lefroy. The Woodman Point light had been made of a high order and distinctive character in order to prevent the possibility of its being mistaken for other prominent lights along the coast in the vicinity of Fremantle. It was very satisfactory to find an engineer, resident in another State and viewing matters from a disinterested standpoint, speak of Fremantle as a port of which the importance in the Commonwealth was second only to that of Sydney, and consequently consider that the sorting-sidings should have been placed elsewhere. While not seeing reason to disagree with Mr. Keele as to the site actually chosen for the dock, and while concurring with Mr. Lefroy as to the evil effects that could ensue through political influences wrongly exercised, especially as such political pressure invariably meant a wrong sacrifice of the interests of the future and of the State to the illusory present benefit of some locality, Mr. Palmer had nevertheless endeavoured to make his Paper a record of work actually done, and to refrain as much as possible from controversial points; hence omission from the Paper of all mention of the dock. It might be added, however, with reference to Messrs. Reid Bell and Keele's remarks regarding the site of the dock and the extension of the harbour, that it had been publicly stated in Western

Australia that Fremantle required and deserved reimbursement for removal of the State railway workshops, by construction of a dock within her boundaries. Mr. Palmer's own proposition of 7 years back was a floating dock—a temporary measure, for in his opinion the harbour was not then (and still was not) in a sufficiently advanced state for construction of permanent docks, of which there must be more than one. Mr. Shields's communication showed that there would be no difficulty as regarded depth for the floating dock; it would have been economical and available long since; it could be removed for use elsewhere when the time was ripe for permanent works; and the interest on the capital sum saved meanwhile would have been a clear asset; or, if it had been imperative to expend money, this could have been better spent on warrantable extension of the harbour-works. There was no doubt that, with the aid of wise counsel, Fremantle could be made a great and cheap port; but in order to attain this with benefit to the State as well as to the interested localities, the questions of providing a ship-channel to Perth and of making Fremantle a large entrepôt must be kept separate. It was easy to do this, as they were not, and never had been, conflicting questions. When they were kept separate it would, in Mr. Palmer's opinion, be realized clearly that the extension of the Fremantle Harbour should be to the south-west and not inside the river: the works already constructed lent themselves to such an extension, and from conversations with the late Mr. O'Connor, Mr. Palmer judged that such had been his opinion also. Mr. Palmer.

*** Messrs. Halligan and King being in Australia, their replies (if any) to the Correspondence cannot be received in time to be included here, but will be printed in a subsequent volume.—Sec. Inst. C.E.

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31 January, 1911.

ALEXANDER SIEMENS, President,
in the Chair.

The discussion upon the Papers by Messrs. Halligan, King, and Palmer, upon Australian Harbours, was continued and concluded.
