Discussion.

Sir Robert Rawlinson. Sir ROBERT RAWLINSON, K.C.B., Vice-President, said members who had heard these elaborate Papers read would have a good deal to contemplate before they could come to any conclusion. They were exceedingly obliged to Mr. Vernon-Harcourt, who was an indefatigable worker—not speculative, but practical—for his Paper. Their thanks were also due to Mr. Partiot for the amount of matter he had brought forward. He (Sir R. Rawlinson) considered, however, that there was too great a mass of matter embodied in the Papers to be discussed with advantage, and that if they had had one-tenth of the matter abstracted and read, they would have been much better able to deal with it. Members might not agree with him in this; but, whether they did so or not, he hoped they would join in a hearty vote of thanks to the Authors of these very able Papers.

Mr. Vernon-Harcourt. Mr. L. F. VERNON-HARCOURT said he had treated in his Paper on four distinct questions with regard to the training of rivers. Three of those subjects were not referred to in Mr. Partiot's Paper, which was confined to the fourth, viz., training-works in tidal estuaries. In order to compare the bars in the case of the Rhone, the Danube, and the Mississippi, the diagrams had been drawn to exactly the same scales. Diagrams were also exhibited of the estuary of the Seine, and the mouth of the Rhone. They were not inserted in the Paper, because plans of the delta of the Rhone, and also of the Seine estuary would be found in fairly recent volumes of the Proceedings.[1] The diagram of the Seine being the last survey made, namely in 1891, was exhibited for the purpose of comparison with the survey of 1875. The diagram showed the lines of sounding of 1875, and also the lines of sounding of 1891. Within that period, they had retrogressed seawards; and deep water was less near the estuary of the Seine than it was in 1875. It would hardly be right for him, at the opening of the discussion, to criticize the Paper of Mr. Partiot, which had been coupled with his own; but he might point out in what way he thought the Author wished his Paper to be discussed. He had had the opportunity of hearing Mr. Partiot express his views at

[1] Minutes of Proceedings Inst. C.E., vol. lxxxii. Plate 6; and vol. lxxxiv. Plates 4 and 5.

Mr. Vernon-Harcourt.

the International Inland Navigation Congress at Manchester in 1890, and also at the Paris Congress in 1892, that a narrow neck was essential for the proper training of rivers through estuaries. Mr. Partiot had been considering the subject for a great number of years; and one of the schemes which had been experimented upon in the models referred to, was a scheme brought forward by Mr. Partiot in 1859 for the completion of the Seine training-works. What Mr. Partiot would undoubtedly wish to be discussed was, how far it was desirable to narrow the outlet of an estuary in order to improve the navigable depth of its channels both above and below. Two illustrations might show what he really would advise. With regard to the estuary of the Ribble, which was funnel-shaped and something like the Seine, Mr. Partiot, if consulted, undoubtedly would recommend the construction of a breakwater from Southport towards St. Anne's, leaving a small neck near St. Anne's, or a breakwater in a reverse direction, starting from St. Anne's, and leaving a narrow outlet near Southport. Also in the case of the Loire, Mr. Partiot had suggested that instead of its being left as it was, it would be desirable to narrow the existing neck near St. Nazaire, in order to improve the channel in the estuary.[1] Those illustrations indicated the points that Mr. Partiot would wish to have discussed. Mr. Partiot had stated in his Paper that the ebb-tide formed the channels above the neck of an estuary, and the flood-tide formed the channel outside. He did not see how that could be accepted as the basis of an argument, because one of the channels above the neck was undoubtedly formed by the flood-tide, whilst the channel outside was mainly formed by the ebb. For instance, the Sloyne channel running up to Eastham, in the inner Mersey estuary, was due to the flood-tide; whilst the channel below Liverpool, out to the bar, was mainly maintained by the ebb. He would not, however, criticize the Paper at that stage, but would leave it to receive that full discussion by members that Mr. Partiot desired.

Sir Robert Rawlinson.

Sir ROBERT RAWLINSON, K.C.B., Vice-President, said that the Papers were so elaborate, and so valuable, that they might be regarded rather for the purpose of reading than of discussion in detail. Mr. Vernon-Harcourt, one of their most valued members, had brought before them a very valuable Paper on the training of rivers; and Mr. Partiot had written upon the subject of

[1] "Étude sur les Rivières à Marée et les Estuaires," H. L. Partiot, Paris, 1892, p. 87.

Sir Robert Rawlinson. estuaries. The French Government had paid much more attention to roads and rivers than the English Government had ever done; and there were, consequently, examples of national river-training, canal construction, and harbour improvement in France such as could not be paralleled in England. The English Government appeared to have given over everything connected with roads and rivers to individuals or companies. The only roads that had absorbed national attention were the main roads in Ireland and in the Highlands of Scotland, which were constructed through the interference and by the aid of the Imperial Government. England was left to the tender mercies of Trust Boards. The first thing that an engineer would do, in considering so wide a subject as rivers and harbours, would be to examine the meteorology of the district, upon which harbours depended for their capability of being formed, and for their maintenance. Meteorology was a very wide subject, and yet its primitive elements were simple. They were three in number: the ocean, which provided the water to be evaporated; the sun's heat to evaporate it; and the atmosphere, to carry and spread the moisture over the surface of the globe. There was also another element that was seldom thought of or discussed, namely, the subtle and irresistible power of the earthquake. They had all heard what it had been very recently doing in Greece. Living comparatively securely upon their own little island, they were very much inclined to forget the gigantic forces that were only slumbering. In the comparatively quiet region of Great Britain, there were annually thirty or forty recorded minor shocks of earthquake, and they were not without some effect. Some scientific men had recently made a very delicate instrument with which to carry out their researches, and when they had perfected it they could not use it, because they could not find a single place on the surface of the earth—on the plains, at the bottom of coal-pits, or upon the mountains—where it could act, in consequence of the incessant vibrations taking place in the earth's crust at every point where it was applied. Cuvier had stated that all the existing mountains—such as the great ranges of the Alps, the Andes, and the Himalayas, and all the active volcanoes—had broken the tertiaries, the tertiary formation being the last geological formation with which they were acquainted. That being so, it might reasonably be considered that, even in England, they were not in a state of permanent repose. They knew very little of the past history of the world beyond a few thousand years, taking the Egyptian monuments as a record.

Even if these periods could be multiplied by thousands, they would take us back a very little way into the history of the crust of the earth. They should remember that, while as engineers they were priding themselves—and properly—upon the magnitude of their works, and the efforts they were making to control nature, there was a point beyond which they could not expect to go, and that they must work in faith and leave the result to the future. Sir Robert Rawlinson.

The training of rivers had not been carried out to any large extent in England, and there were many countries where it was not capable of being carried out to any great extent. In a country where the general surface gradients were steep, he did not see how river-training was to be thought of. In South Africa, for example—a country which should be the hope of many junior engineers—what could be done with the training of some of its rivers which rose in a week from their extreme low-water to 70 feet in height, and became roaring torrents? In Australia, again, for a series of years there might be no appreciable fall of rain upon the surface; and then a series of tornado rains producing roaring torrents occurred, so that rivers that had been dry for years rose vertically 120 feet, carrying off all that was in their way. The only method that an engineer could resort to in a country so situated would be to make somewhere, not much above low water, a track by which bullock wagons and other traffic could cross over in the dry season, as was done in Australia; and then a notice-board might be put up, similar to that of the Welsh engineer—"Take notice that when this bridge is under water this road is impassable." And not only was there that difficulty with regard to rivers, but, in the case of harbours and estuaries, there was the difficulty of the sea. Some years ago a book was written upon raised beaches, in which certain beaches were described which were considered to have been raised above the sea-level in consequence of a gradual rising of the land. The fact was that the sea could and did influence and destroy beaches, and also could throw up beaches which became dry land, from 12 to 30 feet in height, of which the Chesil beach was an instance. At its junction with the Isle of Portland, the beach was about 30 feet above high-water mark. When once in that district, he heard of a brig that was embayed there during a violent onshore storm, which the waves lifted up on the top of the 30-foot beach, and it was launched down over the other side. That showed that the sea was capable of making a beach which might deceive the embryo geologist. It was also well known that the sea could waste. If they examined old English maps of the east coast, the west beaches, or the south, Sir Robert Rawlinson. it would be seen that within historic periods, parishes that were very large had either disappeared or had become very small. On the east coast, the rivers, with one or two exceptions, that flowed into the North Sea were mere stumps of rivers, whose estuaries had all been washed away. Geologists, in fact, stated that the North Sea was a very recent subsidence, and was a very shallow sea. They also said that at no very distant period, Great Britain and France were joined, there being no intervening English Channel. When these things were remembered, they should be very cautious how they entered upon reclamations for forming harbours, and should look carefully at what had taken place, and what might take place in future. He had recently read in *The Times* that the dredging of the channel of the Mersey had deepened it so much that vessels could now come in and go out which previously could not do so; and the reporter stated that he had no doubt that a permanent deep-water channel would be made by the process now going on; but knowing what he did of the estuary of the Mersey, he did not think that the improvement could be permanent. Some years ago he had occasion to hold an enquiry at Wallasey, and he then read the subject up; and having to make a survey of the coast, to see what encroachments had been going on, he found that within a century about 150 feet of the beach had been wasted. A lighthouse which had stood out upon this beach had been taken down; and if the embankment which the Corporation kept up was taken away, thousands of acres inland would be submerged, and the flow of high tides would be from that portion of the sea to, and through Wallasey Pool into the Mersey. In earlier periods there was a water connection between the upper portion of the Mersey estuary, through the lower parts of the Cheshire coast, into the Dee.

He had found that there had been an examination of the coasts of England during the Roman occupation by Antoninus, in which the adjacent rivers flowing down into the sea, such as the Conway and the Dee, and the Ribble and the other rivers northward, were mentioned, but no Mersey. He satisfied himself that at that period there was no direct flow of water from the inland estuary of the Mersey above Liverpool, through the great banks which now impeded the navigation of the river, which was at that time a huge salt marsh. The very name "Mersey" indicated what it was. The upper portion above Liverpool was the "Mere Sea"—"mere" meaning an inland lake—so called because it had no outlet past Liverpool. Liverpool was on the wrong side of the Mersey. If they had been fortunate enough to select the Cheshire shore, they would have had deep water all the way down opposite the site of Liverpool, and would have been able to make entrances for their docks to any depth they chose; but now Liverpool was on a lee and shallow shore. The tide rose 20 feet above the old dock sill, and ebbed 11 feet below it. When he was connected with the docks, the deepest entrance was not more than 7 feet below the old dock sill. Among the rivers that had been improved, the Clyde had been mentioned; and he wished to draw special attention to it, because he regarded it as very liable to be a misleader. Formerly there were only 3 feet of water from Glasgow Bridge to the sea, where there were now 29 to 30 feet, this depth having been gained by dredging and blasting. Glasgow was a large commercial and manufacturing city, which required a deep-water outlet to the sea. It could afford to form that outlet and to maintain it. But if from any cause the work of maintenance was stopped, the Clyde would very rapidly go back to its original condition, with a low-water depth not exceeding 2 or 3 feet. If any young engineer thought that he could deepen some other river in a similar manner, where there were not funds to pay for maintenance, he would only bring mischief and ruin to the place.

Sir Robert Rawlinson.

He wished to refer for a moment to a great work that had been accomplished in their own day—the Suez Canal, which was a passage dredged between the Red Sea and the Mediterranean. It was a great work, but in itself a very simple one. It had been made by spending an enormous amount of money in dredging; and it still existed as a canal because large sums of money could be afforded for maintaining that dredging. If, however, the dredging were stopped, in ten or twelve years the canal would be choked up with sand. The subsidence of the banks and the rising of the bottom were natural evils which men could not control, except by incessant dredging. He had heard it said that the canal was not capable of taking all the traffic that now came upon it; and people had talked of doubling its width. His advice would be that they should do nothing of the kind. If further accommodation was required, a second canal should be made; because if they doubled the present canal, they would increase fourfold the difficulty of overcoming the rising of the bottom. With regard to the Seine, if anyone wanted to know the difficulties that an engineer must experience in working there, he should go and see the condition of the inlet to the Seine at high-water spring-tide, and watch the action of the bore, 10 or 12 feet in height, where the waves were thrown into confusion. Turner had painted a splendid picture which he had called "Quillebeuf," showing that contention of the

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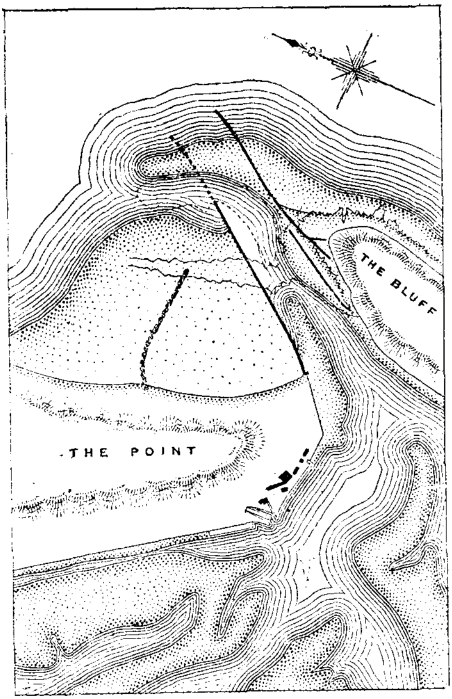
Sir Robert Rawlinson. sea, the waves dashing up, and the birds catching the fish as they were thrown out of the sea into the air. He would be a bold engineer who did much at Quillebeuf at the entrance to the Seine. With regard to harbours of refuge, they might go to the Channel Islands. England had done her best to make harbours of refuge there; but she had given it up in despair. It did not pay, and what had been done was simply lost expenditure.

Mr. O'Meara. Mr. P. O'MEARA said he wished to refer especially to the question of sand-travel, as opposed to the travel of detritus carried in suspension. There was a great difference between the two; and their being mixed up, he thought, had led to very great confusion, and perhaps to some errors, in the designs of ports. The travel of fine sediment in suspension was effected by the action of waves and currents; and it moved along coasts, down rivers, and through estuaries under those influences, deposition taking place whenever a check occurred in the velocity of the stream. The chief method, under those conditions, of improving a harbour was so to manipulate the currents as to prevent that check, and that deposition of sediment. Sand-travel was a totally distinct action, although there were features common to both. Sand-travel he held to be maintained by the joint action of waves and currents. Waves were of two kinds, namely, breakers, and waves of oscillation; and their action was somewhat different. Waves of translation turned into breakers as they approached the shore; and each breaker in falling dug a hole, or, at all events, slightly disturbed the sand. Immediately, the existing current shifted the sand a few feet or inches; and so the process of the action of the breakers on the sand, assisted by the current, went on. He had often seen long stretches of beach, after the retreat of the tide, pitted with holes, a foot or more in depth, in the manner described. The breakers themselves caused such a current; and those currents —whether littoral currents, or currents caused by the action of the waves of translation—carried on the sand so lifted for a few feet at most. But waves of oscillation had also a very powerful influence on the travel of the sand. The first observation which he made on the subject, fifteen years ago, would explain what he meant. In a narrow tidal channel at the entrance of Port Natal, wanting to observe for himself the action of the waves and currents on the sand moving in and out under the action of the tides, he went one day when there was a very slight tidal movement, the velocity not exceeding 6 or 8 inches per second. Not having a diving-dress, he dived to the bottom, with a good-sized stone in his hand, to assist his passage downwards, Mr. O'Meara.

and to have something to lay hold of and keep himself steady while making his observations. The small waves, not exceeding 6 or 8 inches in height on the top, produced a very marked effect upon the sand below, not only on a certain amount in suspension close to the bottom, but also on the sand lying on the bottom. He noticed as each wave was passing overhead, that the sand, instead of flowing along regularly, was oscillating. The sand rolling along the bottom, as well as that in suspension, was oscillating; and he judged that this was from the effect of waves overhead. At the centre of each passage, the velocity was very quick; and at a certain point it became quite suspended, and he almost thought it went backwards. He thought that explained clearly why a slow current, about 6 inches per second, could transport such sand, although it was well known that such a velocity was not capable of moving sand at all, unaided by a wave on the top. He wished to direct attention to the marked influence which even very small waves had in a depth such as that in which he made his observations—9 or 10 feet—in facilitating or causing the movement of sand at the bottom of rivers or estuaries. Judging from what he had observed, he should not be surprised if those waves produced movements at a much greater depth than 21 feet, which, he believed, was generally held to be the limit of the disturbing action of waves. He thought that the effect of sand-travel at much greater depths was very considerable. He thought that 40 or 50 feet was not too great a limit to assign. Even at that depth, he imagined, there was a very considerable movement of sand, when assisted by such waves acting simultaneously with the current. He should be glad if some engineer, who had electric light at his disposal, would extend the isolated observations he had made. By means of a glow-lamp, more knowledge on this point could be attained. The idea of the movement of sand by currents in conjunction with waves was of very easy application, and afforded an explanation of things that were almost impossible to explain by the movement and deposition of silt in suspension. The action of a groyne, for example, was much more easily understood when this idea of sand-travel was applied to it. There was retrogression on one side, and sanding-up on the other as a natural consequence. In the same way, it was evident why, at a bend in a sandy river, the sand was deposited on the convex side and removed from the other. It was simply due to a suspension in the movement of the sand, resulting in an accumulation on one side, and a consequent retrogression on the other, no interruption in the sand-travel occurring on the receding

Mr. O'Meara. side, because of the veering of the waves round the groyne. The effect of the bias of waves on a sandy beach, or of the angle made by their axes with the beach was also worthy of notice. He could point to an instance of such a bias acting in a very singular manner on the coast at Port Natal. The axes of the rollers radiating from the bluff changed their direction according as they moved round its extremity. The mere fact of this bias of the waves in breaking on the shore was sufficient to create a current which moved the sand in the opposite direction to the natural movement which would otherwise be caused by the prevailing currents in the immediate neighbourhood, a little distance out to sea. The Mozambique current passed along the coast nearly from north to south, but the sand moved from south to north; and he ascribed that almost entirely to the action of the bias of the waves. He had heard the late Sir John Coode describe this action, and he thoroughly agreed with him.

Fig. 1.



Scale 1 inch = 500 feet.

PORT NATAL.

Another point to which he desired to call attention was, that on long stretches of coast affected by a prevailing sand-travel, concave indents might be observed followed by convex prominences in the contours of the beach, and that these did not remain stationary, but travelled onwards in the direction of the sand movement. It would be possible to produce such a concavity by raking, or otherwise disturbing a short portion of the beach; a corresponding prominence would at once form on the forward side, and both would travel along the coast for an indefinite time, depending on the influences at work in their course. Similarly, a prominence Mr. O'Meara. preceded by an indent, would be formed by projecting a temporary groyne or other obstacle from the beach, just as the water of a river would be raised behind, and lowered in front, for a short time, by a temporary dam, on the removal of which, a wave would be propagated down the stream.

The baneful tongues of sand which stretched across the mouths of rivers and estuaries on sandy coasts, also travelled in a very remarkable manner. At Port Natal, for instance, the tongue which had now projected itself northward from the bluff, across the outer end of the unfinished works, *Fig. 1*, and which had been drawn into the channel to a certain extent by the inflowing tides, assisted by breakers veering round the present end of the south breakwater, was in existence, somewhat further in, long before the construction of that work. It used to extend itself northward along the line of the bar, pushing before it the navigable entrance channel across the bar, till it reached a point about 50 or 100 yards northward from the loose stone groyne shown on *Fig. 1*. By this time it became cut through at its root, opposite the centre of the straight channel; and immediately the northern channel, at the tip of the tongue, became sanded up, and a new tongue commenced to project itself northwards from the bluff, pushing the new channel onwards as before. This occurred sometimes in less than a year, but frequently took a much longer time. Such tongues receded when the sand-travel was reversed, another tongue advancing from the opposite direction. Small travelling rills or ridges, with a steep slope on the forward side, and a flat one behind, were, as far as his experience went, the invariable concomitants of all sand-travel, except where breakers were at work. When observed in the entrance channel at Port Natal, they were about 6 inches high and 6 feet apart or more, with a depth of water of 9 feet, waves 6 to 8 inches high, and a current of about 6 inches per second.

Whilst agreeing with Mr. Partiot as to the beneficial effects of curved jetties, of moderate length, at the mouth of a river or estuary, receiving the ebb currents on the concave face of the jetty which was on the side nearest to the approaching sand, he could not endorse generally his recommendation of groynes, as typified in Fig. 7, Plate 4. He did not doubt that it was possible to divert, though not to arrest permanently, a sand-travel, by promoting the formation of dunes by means of groynes, as proposed by Mr. Bouquet de la Grye, and palisades movable vertically, as carried out successfully by Mr. Chambrelent at the Bay of Arcachon ; but a heavy sand-travel, of a thousand cubic yards or

Mr. O'Meara. more per day for instance, would soon occupy too much space in the vicinity of the jetties if diverted into dunes; and the proposed groynes would be extremely expensive on a sandy beach at exposed places. The bluff ridge at Port Natal, south of the entrance, was a sand dune 7 or 8 miles long, about 300 feet high, and of very old formation. The beach of limestone, however, on which it rested, seemed to have been raised at least 20 feet above sea-level by elevating forces. There were recent sand dunes on the coast of Brazil, which were half a mile broad or more, 260 feet high in places, and extended for hundreds of miles with occasional interruptions.

He had now sufficiently explained the processes of sand-travel by under-drift, as distinct from silting or over-drift, to enable any one to apply them to the statements and descriptions of Mr. Partiot. He had done so himself very carefully with reference to the works recommended for the improvement of the Seine estuary, and found no difficulty in agreeing with the greater part of Mr. Partiot's very concise and intelligible observations. He recognized the advantage of a neck at, or near the end of an estuary, and thoroughly approved of a contracted entrance as far seaward as possible, with training-walls diverging up-stream therefrom, both of which must tend to diminish the influx of sand, and also of a gradual widening of the channel of a river in its descent, in order to benefit from the resulting regularity in the flow of the stream, and from tidal propagation.

Mr. Shelford. Mr. W. Shelford said that the great number of facts contained in the Papers would be useful to the Institution for years to come, because those who had to study the questions concerned would be more likely to draw a correct conclusion from a large number of facts than from a few isolated ones. He believed that during all the years they had discussed rivers and estuaries in that room, they had never defined what an estuary was from an engineering point of view. Even Mr. Partiot, an old and distinguished French engineer, had commenced his Paper by a definition of an estuary. He had stated that "Estuaries are inlets on or near the sea-coast, containing banks which the tides successively cover and lay bare." That was a very vague and unsatisfactory definition of an estuary, because it only dealt with the visible effects of the forces at work, and ignored their cause. He then went on to say that they might be divided into two classes, viz., "estuaries devoid of rivers, and estuaries into which rivers flow." Estuaries devoid of rivers were rather uninteresting to engineers; whilst estuaries into which rivers flowed were full of engineering operations, and were of great importance to them. He would suggest as a proper definition of an estuary, that it was an arm of the sea having more than one tidal channel. To make the point clear, he would refer to the river nearest at hand as an example, viz., the Thames, which was divided into three compartments—the estuary, the tidal river, and the non-tidal portion. The tidal portion—to say nothing about the non-tidal—had but one channel, up and down which both the flood and ebb passed, and produced the most perfect condition which the circumstances would allow, so that they had a first-class tidal river. But immediately below Sheerness, where the estuary commenced, there were several channels; the main flood-stream came up one, and the main ebb-stream went down another. The consequence was that the flood-tide tended to carry detritus up the river, and the ebb in the other channel tended to carry it down the river, so that there was a continual shifting of sands between the two, a state of things common enough in other estuaries. The Mersey had been also mentioned several times as a very interesting example. The upper estuary of the Mersey extended from Liverpool to Runcorn; the tidal wave was impelled through the channel at Liverpool on to the Cheshire side of the Mersey; and the flood-tide, by its own momentum, travelled along the line of least resistance to Runcorn. The difference of level between the two points was, of course, the same for the incline on the Cheshire side, and that on the Lancashire side; but as the Cheshire side was 50 per cent. longer than the Lancashire side, the greater declivity was on the Lancashire side. The normal result was that the ebb-tide necessarily flowed down the Lancashire side, because it was the shortest route. It was a principle that should not be ignored in all estuaries, that the ebb-tide always took the shortest practicable route to the sea. This he could illustrate in a very simple way. If they stood on a sea-shore, the wind blowing obliquely, and the waves coming obliquely upon the beach, each wave could be seen coming up in the direction in which it was driven; but it invariably retired at right angles, being the shortest route to the water. The tidal wave acted much in the same way. A great deal might be said about Mr. Partiot's view as to the importance of necks, whether artificial or natural, at the mouths of estuaries; but he would not go into the subject, much less generalize upon it, as by far the safest practice was to judge each case upon its merits. He thought that the definition he had given of an engineer's idea of an estuary, and the principle of the ebb-tide taking the shortest route to the sea, where it was possible to do so, were perfectly Mr. Shelford.

Mr. Shelford. safe and sound engineering. Mr. Vernon-Harcourt had referred to the London International Maritime Congress, in which he had taken an active part. What had struck him (Mr. Shelford) at that Congress, was that the improvement of entrances to ports was now very largely performed by suction-dredging. It appeared that the ports on the coasts of France and Belgium were being improved in that manner. Undoubtedly, the best example of that kind of dredging was on the Mersey; and it had been so far successful. The last accounts showed that the depth over the Mersey bar had been doubled. In America, also, they had been doing a great deal in the way of improving their harbours by suction-dredging. To those who had been accustomed to look upon training channels as the only means of getting rid of sand-banks, it was a novelty to find suction-dredgers taking the work out of the hands of the trainers.

Mr. Wolfe Barry. Mr. J. Wolfe Barry, Vice-President, as one of the British representatives on the International Technical Commission of the Suez Canal, would like to correct an idea of Sir R. Rawlinson's, that the question as to whether the canal should be widened, or two canals formed, was now under consideration. That matter had been settled, after a very considerable conflict of opinion, about six or seven years ago. The British representatives, Sir Charles Hartley and the late Sir John Coode, with others, were strongly of opinion that the canal should be widened, in opposition to the scheme which was energetically supported by many foreign engineers, that two canals should be made. The widening had been in progress ever since, and was a great success both from an engineering and nautical point of view. None of the difficulties which Sir R. Rawlinson feared had been experienced; and the amount of subsidence of the banks, and raising of the bottom had been very trifling. The work of dredging for the maintenance of the canal was not great, certainly not nearly so great as was anticipated by many engineers in the earlier years of the canal, and did not weigh at all heavily upon the company. The chief amount of dredging took place in the outlet-channel at Port Said, where considerable dredging was required, giving rise to anxiety from time to time. The entrance was protected on each side by two long piers, which had been prolonged beyond their original length; and it was foreseen by many engineers, including the late Sir John Hawkshaw, who reported on the subject in 1863, that there was a risk of the sand, drifting eastwards, accumulating on the western side and overlapping the entrance, which had to some extent taken place from time to time. The piers being in rough water, exposed to winds and storms, dredging beyond their extremities proved troublesome and expensive; but the growth of the deposit had of late years been to a very great extent arrested by the removal of the crest of the west pier near its shore end. The upper part of the pier having been thus lowered in different places from time to time, the sand consequently came into the channel where it could be dredged, instead of accumulating beyond the pierheads. The dredger working in comparatively smooth water, there was no difficulty in dealing with the deposit. The work had been in progress for some years; and he believed the whole Technical Commission were completely satisfied that this difficulty had been overcome, and that they might be certain that the mouth of the canal could be satisfactorily kept open, and, in fact, deepened. Also, apart from the widening of the canal, a great additional depth had been given at the same time. On the strong representations of the British representatives, the canal was now being carried to a depth of 28 feet; and it was hoped that before long there would be a depth of $29\frac{1}{2}$ feet from shore to shore. He had mentioned these facts because he thought there might be some apprehension, from Sir Robert Rawlinson's remarks, of a risk to that important water-way from the widening. Instead of there being any risk of the bottom rising, a greater depth was really being gained than had previously existed; and the depth would be increased from time to time, so that the water-way would be very greatly improved by the works now in progress. Mr. Wolfe Barry.

Mr. E. D. MARTEN said that he had recently carried out a small, but successful training-work upon the semi-tidal portion of the Severn, a few miles above Gloucester. The Severn Commissioners had been improving the navigation of the river for some 30 or 40 miles; and among other things, they had had to increase the navigable depth of the river, from a minimum of 6 feet at low summer level, to 10 feet. For the most part, a certain amount of dredging merely had been required; but there had been some rather difficult places to deal with, one of them at Wainlode, 6 miles above Gloucester, where there was an awkward bend, the bed of the river consisting of hard marl rock. The rock shelved down to the convex side of the bend, so that on the concave side there were only a few inches of water at low summer level; while formerly there was barely a depth of 6 feet on the convex side. Floods and freshets coming down the river, impinged on the concave side; and consequently the old channel, on the convex side, was almost always impeded by silt, and was very Mr. Marten.

Mr. Marten. difficult to keep open; which difficulty would have been much increased after deepening the channel from 6 to 10 feet. It would have been very expensive to make a cutting with a 10-foot face through the rock on the concave side, as the channel was 300 feet wide round the bend, though only 150 to 200 feet in width above and below. A training embankment was, therefore, formed on the concave side, to divert the floods and freshets on to the convex side, and so scour out the proposed 10-foot channel, by sinking a number of old canal boats end to end along the line of the river face of the proposed embankment. These boats only cost about £5 each, and were sunk in such a position that their tops just stood above the water at low summer level. They were held down by short piles driven into the marl rock, and were filled with the rock which was dredged from the channel. The whole of the space at the back of the boats was also filled with dredged marl rock. These works diverted the ordinary summer flow down the new channel, but this flow alone was not sufficient to keep open the new dredged channel. Accordingly, in order to direct the flood waters also down the new channel, five cross-dykes were made, such as Mr. Vernon-Harcourt had referred to in his Paper, by placing an old boat on the newly-formed embankment, nearly at right angles to the stream, and depositing over it the hard marl rock dredged out of the channel, and so forming a mound at each place. The dykes pointed slightly down-stream, and not up-stream as in the case described by Mr. Vernon-Harcourt. He thought it would be interesting to know what the advantage was of making them point up-stream. If it caused silting to take place between the dykes, it would be very advantageous, because it was expedient that the spaces between the dykes should fill up and become solid land. The training embankment and the dykes had kept the channel perfectly free from silt, which had been kept dredged 10 feet deep, and with a face of from 4 to 6 feet through the hard marl rock round the convex side. That channel had now been completed for more than a year; and when he went over the site a few days ago, wherever he dropped a sounding-rod on the floor of the new channel, it gave out a hard, ringing, metallic sound, showing that the whole of the dredged channel was as free from sand and silt as the flagstones in Westminster Hall. That same channel, when the depth of water was 6 feet only and before the training embankment was made, used to be a constant source of anxiety and trouble, owing to the manner in which it silted up. On the Severn they had to be very careful to place nothing in the river which would tend to increase at all the floods on the meadow lands above. That difficulty was got over here, partly by the increased sectional area resulting from the dredging, and partly by the improved hydraulic mean depth which was obtained; so that, notwithstanding the loss of sectional area caused by the embankment, the channel was now more capable of discharging floods than it was before the works were undertaken. The only anxiety they now had about the matter was, that for about 50 yards at the tail-end of the improved channel, a little bed of sand and silt tended to form. If this shoal should increase, it would only be necessary to carry the embankment on for a very short distance, because 20 or 30 yards past where the little shoal was forming, the river became 20 feet deep, and there was no danger of any further deposit. Mr. Marten.

Mr. G. F. Deacon remarked that the importance of making observations concerning the transport of sand by running water had been referred to by Mr. O'Meara. He had conducted a series of such observations for the Mersey Docks and Harbour Board, in connection with the Manchester Ship-Canal Bills of 1883–4–5, the results of which he would endeavour to summarize. Many abortive trials were at first made; but an apparatus was ultimately devised which enabled him to obtain perfectly trustworthy and conclusive results. The observations were made in a long flat-bottomed trough with glass sides, by means of which the behaviour of the sand could be accurately observed. The sand was from the estuary of the Mersey, the quantities moved were weighed, and the surface velocities of the water were carefully measured. When water flowed with a steadily increasing velocity over a surface of such sand, fine pieces of broken shell were first moved; and the surface velocity required to produce such movements was considerably less than 1 foot per second. At such velocities, however, the sand proper was perfectly stable, and however long the flow continued it remained undisturbed; but the fine pieces of shells at the surface of the sand moved in spasmodic leaps, accumulating wherever the velocity was somewhat less. Mr. Deacon.

The first movement of sand began at a surface velocity of 1·3 foot per second. This movement was confined to the smaller isolated grains; and if the same velocity was maintained, the grains so moved ranged themselves in parallel bands perpendicular to the direction of the current, each band taking the form of the well-known sand ripples of the sea-shore or sand-bottomed stream, with its flat slope upwards, and its deep slope downwards in the direction of the current. At this velocity the profile of each sand ripple had a very slow motion of translation, caused by

Mr. Deacon. sand particles running up the flatter slope and toppling over the crest. The steep downward slope was therefore being constantly advanced at the expense of the denudation of the less steep upward slope. At a surface velocity of 1·5 foot per second, the sand ripples were very perfect, and travelled with the stream at a velocity of about the $\frac{1}{2160}$ part of the surface velocity of the water (*Figs. 2* and *3*). At a surface velocity of 1·75, the ratio

Fig. 2.

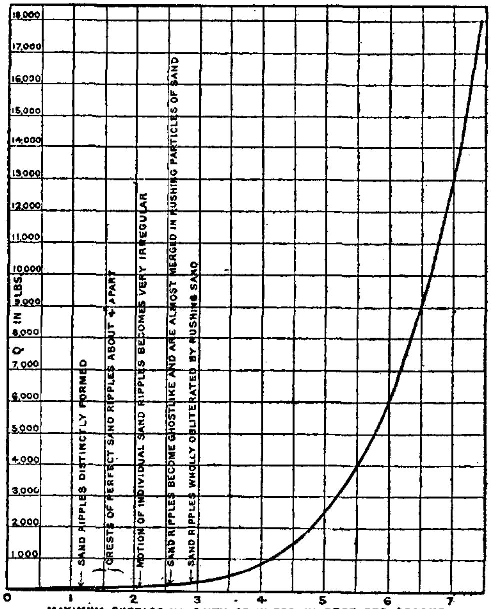
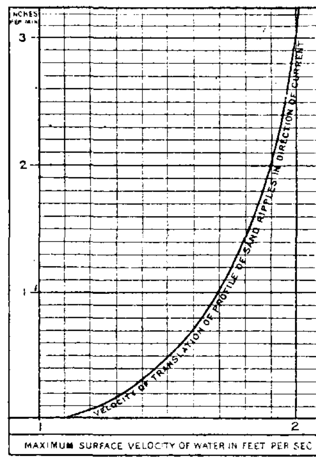


Fig. 3.



NOTE.—Q is the weight of sand which, in a channel of uniform velocity, is capable of being moved across any section per hour, per foot-width of stream. If, at the rate Q, the supply of sand is maintained up to the given section at the up-stream end of the sand-bed, the same weight will be continuously discharged at the lower end of the sand-bed without any change of section. An increase of velocity at once deepens the section throughout until another condition of stability is reached, which will be maintained so long as the new value of Q is supplied at the upper end of the sand-bed.

was reduced to about $\frac{1}{1050}$, and at a surface velocity of 2 feet to $\frac{1}{480}$. A critical velocity was reached when the surface of the water moved at 2·125 feet per second, when the sand ripples became very irregular, indicating greatly increased unsteadiness of motion of the water. Up to this point, the whole amount of scour was represented by the volume of the sand-waves multiplied by an exceedingly low velocity, always less than the $\frac{1}{480}$ part of the surface velocity of the water. At about this critical velocity of

2·1 feet per second, the particles rolled by the water up the flat slope, instead of toppling over the steep slope, were occasionally carried by the water direct to the next crest; and as the velocity of the water was gradually increased, an increasing bombardment of each crest from the crest behind it took place. At about 2·5 feet per second, another critical velocity was reached, and many of the little projectiles cleared the top of the first, or even of the second crest ahead of that from which they were fired. At surface velocities of 2·6 to 2·8 feet per second, the sand ripples became more and more ghostlike, until, at 2·9 feet per second, they were wholly merged in particles of sand rushing along with the water in suspension. After this the scour was of a totally different character; the sand and water became mixed, and a constant process of lifting, carrying, and depositing of individual particles ensued, the sand being stirred to a depth and lifted to a height dependent upon the velocity. Mr. Deacon.

Attempts had been made to determine the law of scour theoretically, and the weight of sand moved had been stated to be proportioned to the sixth power of the velocity of the water. He believed the method of determination to be fallacious; and the result was not justified by his observations, which showed that, within the limits of the experiments, the weight of sand and silt transported was proportional to the fifth power of the surface velocity, possibly a little more. These results were shown in *Figs. 2* and *3*. The larger curve gave the surface velocity of the water, and the corresponding weight of Mersey sand and silt scoured from the up-stream end of a shoal, and conveyed in the direction of the stream, so long as its velocity was maintained. Under each condition of velocity and corresponding weight of sand moved across any given section, a uniform channel was maintained.

In considering the effect of proposed works, it seemed to him of the utmost importance to have regard to the fifth powers of the observed or probable resultant velocities, as the case may be, at various cross sections. For example, it could be shown to be impossible, in the present condition of the Mersey estuary, for any permanent deposit to occur opposite Liverpool; but it could also be shown how exceedingly small a loss of tidal capacity, in the basin of the upper estuary, was necessary to so far reduce the velocity at cross sections above Liverpool, as to cause the banks now exposed at half-tide to creep down towards the deeper channel between Liverpool and Birkenhead, and thus in their turn to aggravate the reduction of capacity and reduce the scour of the bar. He had

Mr. Deacon. specially applied this mode of investigation to cross sections of the Mersey, but it was equally applicable to other cases.

The general result of this investigation, involving the fifth power of the velocity, applied to sand or silt of all degrees of fineness, and he believed (within the limits of surface velocities up to 10 feet per second) to all depths also; but the actual quantity of sand or silt transported depended upon the size of the individual particles, and upon the depth of the water.

The absolute weights, therefore, of material given were only true under the conditions of the particular experiment in question; and they might be much larger in practice, especially where, as in the case of the Mersey, enormous quantities of fine silt were held in suspension up to the surface of the water, and where, during each spring-tide, no less than 100,000 tons of solid matter were brought into the estuary, while on the ebb a corresponding quantity was again returned to the sea.

Mr. Vernon-Harcourt. Mr. L. F. Vernon-Harcourt, in reply, said that Sir Robert Rawlinson had referred to geological changes, but he thought that engineers must be content with things as they were at the present time, and leave to their successors to deal with whatever changes they might afterwards find. The French engineers had been bold enough, more than a quarter of a century ago, to carry the Seine training-works beyond Quillebeuf, in spite of the difficulties described by Sir Robert Rawlinson. Rather more than ten years ago, he had, in a discussion in that room, expressed the opinion that the widening of the Suez Canal would be in every respect preferable to the construction of a second canal; [1] and he was glad to hear from Mr. Barry that it was being accomplished successfully. With regard to material in suspension, and material which was travelling along at the bottom, both were found in the Mississippi and the Rhone. There was in most rivers, no doubt, some material that was carried in suspension, and some material that was rolled along the bottom. In most cases, the material that was rolled along the bottom was more difficult to deal with in these rivers than the material in suspension. In the case of the Rhone, in going over from the Port of St. Louis to Marseilles, in a steamer, though they were some distance from the mouth of the Rhone, they came across the layer of yellow alluvium from the river in suspension on the surface; and by the stirring up from the screw of the steamer, the bluish waters of the Mediterranean could be seen underneath. Mr. O'Meara had, however,

[1] Minutes of Proceedings Inst. C.E., vol. lxxvi. p. 239.

Mr. Vernon-Harcourt.

referred more to the travel of sand along the coast. In the case of tideless rivers, the material was brought down by the rivers themselves. Generally, the travel of sand along the coast depended mainly upon the direction of the prevalent and strongest winds in the locality, because the winds raised the waves, and the waves carried the material along the coast. In dealing with any harbour or river, the direction of travel, the density, and the amount of the material should be considered. Mr. O'Meara had also mentioned that he thought the movement of material was supposed only to occur down to a depth of 21 feet. In a Paper which Mr. Vernon-Harcourt had read before the Institution in 1873, upon Alderney Harbour, he had mentioned that he had found, as far as one could judge, that the movement of the rubble base of the Alderney breakwater ceased at a depth of something like 21 feet below low water.[1] He had, however, heard since then, that at Tynemouth the movement of rubble and large blocks took place at even a greater depth. Sand was a very different thing from rubble; and if rubble could be moved by waves at 21 feet below the surface, no doubt sand could be moved at a considerably greater depth. Mr. O'Meara approved both of funnel-shaped estuaries, and also of estuaries with a narrow neck. There might be cases where a narrow neck was advisable, but generally speaking one could hardly approve of both those systems of training-works for improving an estuary.

The difficulty as to the definition of estuaries had been mentioned by Mr. Shelford. In Section 4 of the International Inland Navigation Congress at Paris in 1892, they had proposed to define estuaries, but they had been unable to arrive at a satisfactory agreement on the subject. They came to the conclusion that they could not define an estuary, but that everybody knew what an estuary was.[2] Then with regard to the question of the ebb-tide, mentioned by Mr. Shelford, taking the shortest direction. He quite agreed with him as regarded the Mersey that the flood-tide ran up the Sloyne Deeps towards Eastham, and that the ebb-tide generally skirted the opposite shore. In the case of a winding river it would be found that the ebb-tide followed the sinuosities of the river, and that the flood-tide took a somewhat straighter course, because the ebb-tide followed a course corresponding to that of the ordinary discharge of a river without any tide, whereas the flood-tide would flow up in a different, and somewhat straighter

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[1] Minutes of Proceedings Inst. C.E., vol. xxxvii. p. 74.

[2] V^{me} Congrès International de Navigation Intérieure, Paris, 1892, Procès-Verbaux des Séances des Sections, p. 596.

Mr. Vernon-Harcourt.

course; and, as he had mentioned in his Paper, blind channels would be found in many wide tidal rivers, which were due to the flood-tide, the main low-water channel being due to the ebb. [Mr. SHELFORD said he quite agreed as to rivers, but he had spoken of estuaries.] He (Mr. Vernon-Harcourt) was thinking of a river with which he had had to do—the Usk, though the wide outlet of that river could not quite be called an estuary—where the flood-tide could be seen forming blind channels. Even in a wide estuary, however, the ebb-tide could not be said to take invariably the shortest route to the sea, for the low-water ebb-tide channel wandered about all over a wide estuary in its constant alterations of course. Thus, in the inner Mersey estuary, though the low-water channel was usually near the Lancashire shore, it ran close along Ellesmere Port, on the Cheshire shore, in 1875; and, in the Seine estuary, the main low-water channel was sometimes close to Havre, and at other times close to Honfleur on the opposite side of the estuary. The course of the flood-tide was influenced by the direction in which it approached an estuary, and by the form of the estuary; whilst the ebb-tide, though impelled by gravity, and therefore tending at first to adopt the straightest course to the sea, was soon diverted, as the tide fell, into the deep low-water channel, which constantly shifted under the action of winds and the erosion of sandbanks; and the main object of training-works in an estuary was to direct the flood- and ebb-tides into one channel.

With regard to Mr. Marten's question about the dykes in his case pointing down-stream, and in the case of the Rhone pointing up-stream, he must mention that the dykes that pointed up-stream in the Rhone were dipping cross-dykes. The reason why they were made, practically in every case, pointing up-stream, was, he believed, in order to make the current converge towards a central channel, because the great object on the Rhone, when there was very little water, was to get a deep channel, and as much water as possible into the centre of the river.

Narrow necks had been advocated by Mr. Partiot because, from a study of estuaries, he had found that they were the best for estuaries. On previous occasions when Mr. Partiot had quoted the Mersey at international congresses, Mr. Vernon-Harcourt had suggested that he thought English engineers would hardly quote the Mersey as an instance of a satisfactory estuary. With regard to Mr. Partiot's proposal with reference to the Seine, the objection was this, that if a narrow neck were formed at the mouth of the Seine, putting aside all questions of expense, by the making of a breakwater from Villerville

Mr. Vernon-Harcourt.

nearly to Havre, a large quantity of material would be brought in in suspension, through the narrow neck, as he had himself seen it on the Havre side of the estuary. That material would be carried up the estuary by the rapid current through the narrow neck, would settle in the estuary as the current slackened, and by degrees silt up the sluicing basin formed by the enclosed estuary. Undoubtedly Mr. Partiot would get a large depth in the narrow outlet of the river, and probably would maintain it for a considerable time; but he proposed also to put training-walls into that estuary. Now Mr. Partiot had stated in his Paper, that he quite agreed with the English engineers that it would have been undesirable to carry out those training-walls in the Mersey which were proposed for the Manchester Ship-Canal in 1883 and 1884. If Mr. Partiot agreed with the view that it would be a disadvantage to put training-walls in such a situation, Mr. Vernon-Harcourt should have thought Mr. Partiot must admit that, in the case of the Seine, training-walls put into the estuary, after it had been converted into an estuary with a neck, would produce the same results, and that the estuary of the Seine would gradually silt up. Mr. Partiot had also referred to the works at the mouth of the Tyne and the Liffey, which he called artificial estuaries. Converging breakwaters in those situations Mr. Vernon-Harcourt thought no one could doubt were very satisfactory. There was a sheltered place formed where the bar could be dredged away, as had been done in the case of the Tyne; or, as in the case of the Liffey, it was possible by concentrating the tidal currents at the outlet to scour away a certain portion of the bar. The artificial estuary of the Liffey, as it was called, had been increased in tidal capacity by dredging inside the estuary itself; therefore it had been possible, in this case, to maintain the tidal capacity of this artificial estuary. But that, in his opinion, was quite a different thing from converting a wide estuary into an estuary with a narrow neck.

Another subject to which Mr. Partiot had referred in his Paper was the improvement of rivers by dredging, which he seemed to think was undesirable. On the other hand Mr. Vernon-Harcourt believed the results of recent works tended to show that dredging could be carried on economically and advantageously to a far greater extent than formerly. Dredging, as stated at the London International Maritime Congress last year,[1] had been carried on successfully so far upon the Mersey bar, which

[1] International Maritime Congress, London, 1893, Section I., Minutes of Proceedings, p. 60.

Mr. Vernon-Harcourt. was so much exposed, that if anywhere dredging might not be supposed to be likely to be successful it would be there. They had been able hitherto to lower the bar considerably in a somewhat narrow channel; and, provided they had sufficient funds to continue to carry out those works, there was no reason why they should not be able to maintain an improved navigable depth over the bar. It was a question of maintenance; and until the bar had been lowered to the full extent that was necessary, it was impossible for anybody to say how much that maintenance might be. Nevertheless he believed it would be an advantage to Liverpool, not merely in deepening the channel across the bar, but also in maintaining the position of the navigable channel, which, as they knew, tended to shift; and, by deepening it, the main channel would tend to remain in the deepest part. When it was remembered what had been done upon the Clyde, and still more what had been done upon the Tyne, it must be acknowledged, in spite of Mr. Partiot's views, that dredging, as well as training-works, afforded a most valuable means of improving rivers.

Mr. Partiot. Mr. H. L. PARTIOT desired to reply first to Mr. Vernon-Harcourt, who had recalled the fact that, at the International Inland Navigation Congress at Paris in 1892, he had expressed surprise that the Mersey was cited as a good river, whereas it was one of the worst estuaries that could be named, and that a bar existed at the end of its outlet channel. He (Mr. Partiot) did not think that he had ever stated that the state of the Mersey was satisfactory; but he had pointed out at the congress that the existence of the bar did not invalidate the law which he desired to verify, and in accordance with which a channel had been formed below the neck, extending $9\frac{1}{3}$ miles beyond Liverpool with depths of 33 feet.[1] This law was, that in estuaries with a neck, a great depth was found in the neck itself, and also deep channels, extending generally to great distances from the neck, both into the estuary and also towards the sea. This natural fact was proved by observations of this class of estuary, of which he had given fourteen examples in his Paper. He could add sixteen others, namely, Western Port, Corner Inlet, and Port Phillip in Australia, the Bay of Richmond in North America, Malamocco in the Adriatic, Mitindani in South Africa, Exmouth in England, Dornoch Firth and Loch Fleet in Scotland, Lorient estuary in France, the Minho and Mondego rivers, and the Bays of Setuval and Portimaon in

[1] V^me Congrès de Navigation Intérieure, Paris, 1892, Procès-Verbaux des Séances des Sections, pp. 621, 622.

Portugal, the Cameron river on the west coast of Africa, and the Rio Grande do Sul in Brazil; and there must be many more which he did not know. With the exception of variations due to local causes, all these thirty examples conformed to the law which he had indicated. The instances of estuaries devoid of rivers which he had cited, showed that the law did not depend on the rivers which flowed into the estuaries, but on the existence of a neck. These estuaries, however, had not appeared to enterest engineers, because ports could be established on them, like Poole Harbour; or sometimes even these kind of estuaries could be artificially created for the requirements of navigation. The estuaries to which he had referred had existed since prehistoric times, although the entrances of most of them were exposed to the inroad of sand; and experience thus proved that these estuaries maintained themselves, or only filled up extremely slowly. This was readily explained, for in a funnel-shaped estuary, the flood-tide flowed in over all the width of the entrance, bringing in sand along this great extent; and the ebb-tide dispersed itself over this same width, and lost the greater part of its power to carry back the sands to the sea. When the entrance, however, was narrowed, the sands could only come in along a less length of beach, and the action of the ebb was concentrated for throwing back the sand on the coast; and there was a certain width of neck for which this concentration sufficed to carry out to sea, not merely the sand brought in by the flood, but also the materials brought down by large rivers, such as the Garonne and the Dordogne. If, therefore, a neck was formed at the entrance to an estuary, it was certain that its effects would be in conformity with the same laws as those which had been manifested by the examples he had given, namely, a great width in the neck, deep channels of a considerable length, both above and below the neck, and the maintenance of the estuary with silting up. A bar might be formed inside estuaries, as found in the Foyle near the Flats bank, and in the Gironde above Richard; and it would therefore be advantageous to construct training-walls to lead the river beyond this bar, within the zone of action of the neck, as shown in Fig. 9, Plate 4. A directing training-wall might be useful beyond, to guide the channel, or to prevent its wandering away from a port on the shore. It might also be expedient to form a false channel outside the regular channel, whose wanderings might combine with the other causes in keeping down the level of the sandbanks; though the Jude estuary, and Arcachon Bay proved that this was not indispensable. The aim of his Paper was to deal merely with the theoretical Mr. Partiot.

Mr. Partiot. question of the improvement of estuaries. He must, however, remark that an investigation of the subject, quite independent of the question of the Seine, had led him to propose a system of improvement for estuaries, Fig. 9, Plate 4, which much resembled the scheme which other considerations had caused him to prepare for the Seine.

Both observation and calculation proved that contractions did not prevent the discharges of tidal rivers and estuaries from increasing continuously down to the sea, and that necks did not appreciably impede the influx of the tide into rivers and estuaries. Observations taken on the Garonne indicated that high water of springs and neaps reached the same level at Bordeaux as at Pointe de Grave; and the low-water line at spring-tides was only about $1\frac{2}{3}$ foot higher at Bordeaux, whilst at neap-tides, it was about $3\frac{1}{4}$ feet lower there than at the mouth of the Gironde. The tidal action, accordingly, was not hindered by the neck at Pointe de Grave. Calculations furnished evidence of this fact, for the best formula for the average velocity of the flow of a river, was $U = \sqrt{\frac{h\,I}{l}}$, deduced from Prony's formula, which showed that in two equal rectangular sections, with equal slopes, the discharges varied up to a certain limit as the square roots of the depths; and the depths in the neck at Pointe de Grave reached about 100 feet below zero. Lagrange's formula also, $K = \sqrt{g\,h}$, giving the rate of propagation of waves, showed that these velocities followed nearly the same laws. The great depths of necks, therefore, explained why necks of suitable width and depth did not offer any serious obstacle to the discharge of the water flowing into and out of an estuary, or to the propagation of the tidal wave up a river. His observations on the Gironde, given in a previous publication,[1] showed that the velocity of the currents in necks was not a hindrance to navigation, because the neck was scoured, and the section thereby increased, when this velocity exceeded a fairly moderate limit.

He had pointed out in his Paper that a current which passed from a narrow neck into a much wider space lost its velocity, and exerted only a feeble scouring action on the bottom immediately in front; and he had explained how the channels above and below the neck were due to the drawing of the sand towards the neck. The Rio Grande do Sul in Brazil appeared to him to give a striking illustration of this fact, where depths of $16\frac{1}{2}$ feet did

[1] "Etude sur les rivières à marée et les estuaizes," H. L. Partiot, Paris, 1892, p. 58.

not extend more than 2 miles below the neck, the rise of tide being Mr. Partiot. only 2 feet; whereas depths of over 33 feet were found up to San Juan del Norte, 8 miles above the neck. On the Mersey, where the river was small, and the tides had a large range, the channels of the upper estuary were short, whilst the outlet-channel had great depths for over 9 miles.

Much time had been devoted by Mr. Vernon-Harcourt to small-scale models, with which he had carried out experiments in relation to the Mersey and the Seine. The model experiments undertaken at Rouen had furnished results which were only imperfectly known; but nevertheless he could say that those which had been ascertained had varied considerably, according to the duration of the experiment, and the manner in which new sand was placed in the model. He thought that Mr. Vernon-Harcourt would have obtained different results with his model if he had continued each of his experiments for a longer period; and he would, therefore, urge the importance of the precautions necessary, in using small-scale models, to obtain useful results.

His definition of an estuary had not been considered sufficiently exclusive, and consequently as somewhat vague. He was fairly in agreement with Mr. Shelford on this subject; but it seemed to him necessary to furnish a definition, because some engineers did not consider the inner estuary of the Mersey above Liverpool, and the estuary of Lorient above Port Louis, to be estuaries. On the other hand, some wide spaces inland, such as the branches of the Odet below Quimper, and Lédanou were true estuaries. A definition of estuaries proposed at the Paris Congress of 1892 by Mr. Mengin-Lecreulx had been rejected, and only applied to estuaries with rivers. His definition, however, was general, but did not include the wide spaces in rivers where the tide did not leave extensive sandbanks uncovered at low water; and, such as it was, he considered it worthy of acceptance.

Correspondence.

Mr. N. de Sytenko observed that, whilst acknowledging the Mr. Sytenko. clear views expressed by the eminent Authors, felt bound to raise some minor objections. He did not consider it right to take the Rhone regulation works as a model of the system of improving the navigable condition of the principal rivers of Europe, though the Rhone had, indeed, been improved by means of submerged dykes, in conjunction with parallel training-walls, so that a