

not extend more than 2 miles below the neck, the rise of tide being 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. Mr. Partiot.

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 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 Mr. Sytenko.

Mr. Sytenko. minimum depth of $4\frac{1}{2}$ feet had been obtained in place of $1\frac{1}{2}$ foot, which was the available minimum depth up to 1876. The physical conditions, however, of the Rhone differed materially from those of most of the European rivers which had been greatly improved within recent years. The average fall of the Rhone being 1 in 2,000 between Lyons and its mouth, was much larger than the fall of the Elbe, the Oder, and the Weser; and its rate of flow also, which amounted in some places to 20 feet per second, was decidedly greater than that of the other rivers of Europe. The small discharge of the Rhone, moreover, and its relative uniformity during all the period that navigation was practicable, and the solidity of its banks, caused the alluvial matter brought down by the river to be of a hard nature, the greater portion of which reached the sea without disintegration. The success of the Rhone regulation works possessed at the time an importance, owing principally to regulation, in this special instance superseding canalization, which till then had been considered the most efficient method of improvement, though also the dearest. In fact the Rhone, in the central portion of its course, might be said to lie between two groups of rivers, one of which required to be improved by canalization and the other by regulation. On the other hand, when, within the last ten years, the improvement of the great rivers of central Europe was undertaken, which had a very sluggish flow and a moderate fall in a sandy stratum, it became necessary to modify the regulation works. The engineers, relying upon theoretical considerations in their schemes of improvement, tried to form a normal channel which should contain all the water discharged at a given section, whilst preserving the requisite depth for navigation. It was hoped that this channel might be formed by half cross-dykes, starting from the banks and from longitudinal training-walls submerged during floods. Later on it was realised that the object had been only half attained, and that to secure a complete improvement, it was essential, in forming the normal channel, to take into account the minimum summer discharge, as well as the average discharge. During the low stage of the river, the trained channel should direct the current so as to afford the necessary navigable depth along the whole length of the navigable river; and this depth being generally secured during the period of average discharge, the changes in the channel produced during its somewhat prolonged period had a great influence on the depth. Accordingly, the destructive and creative power of the current of average discharge should be employed, by means of suitably designed

training-works, for the formation of a proper channel. The Mr. Sytenko. problem was considerably complicated in dealing with a river of such a unique character as the Volga in its central portion; and if the system of regulation adopted for the improvement of the great rivers of central Europe was applied to the Volga, the expense would be enormous, whilst success would be doubtful. The Volga, indeed, surpassed all the other European rivers, both in its gigantic dimensions, and the immense quantities of silt which it was constantly shifting; and, consequently, irrespectively of the cost, its improvement involved a much more complicated problem than any works hitherto carried out on the other European rivers, and one which the most eminent Russian engineers had not yet succeeded in solving.

He was fully convinced that, in this case, experiments made in imitation of those which Mr. Vernon-Harcourt had so ingeniously carried out in his investigations with regard to the outlet of the Seine, could not fail to lead to positive results. Mr. Vernon-Harcourt, however, had to deal with tides, which he could reproduce with tolerable facility; whereas a tideless river, like the Volga, was quite a different matter. The deposits produced in Mr. Vernon-Harcourt's model, corresponded to some extent to the phenomena which actually occurred in the Seine channel, both in its open, as well as in its trained portion. Those results were obtained by imitating mechanically the flow and ebb of the tide; but the difficulty of imitating, in a model of limited size, the displacements of deposit which produced the shifting shoals of the Volga, was all the greater since the changes in the velocity of the current occurred very rarely, though generally regularly and during a fairly long period.

As he was himself proposing similarly to carry out, on simplified models, the experiments necessary to investigate the possibility of arranging fixed groynes in a movable bed for the purpose of intercepting the silt and alluvium carried down by the current, which was more rapid at the summit of its parabolic course, and removing the deposits by constant dredging with a suction dredger, he must acknowledge the great difficulty of establishing clearly certain laws as to the formation of those deposits. Nevertheless, it was very desirable to investigate the subject of the formation of deposits in the channels of non-tidal rivers by the experimental method, which, as proved by Mr. Vernon-Harcourt, gave fairly positive results, and not merely theoretical, in the case of tidal rivers. So long as the laws concerning the deposit of silt and alluvium carried down by a river were not established on a

Mr. Sytenko. tolerably incontrovertible basis, it would be difficult to give the preference to the views of either Author as to the improvement of estuaries; but, nevertheless, it was sometimes of great importance to take account of the velocity of flow of a river.

Mr. Willcocks. Mr. G. W. WILLCOCKS remarked that, in the improvement of rivers, navigation, arterial drainage, and water-power were always considered. The fisheries, however, at times of more value than all these three, appeared to be totally lost sight of. Rivers should be as valuable for producing food as the farms on dry land; and the engineer should, therefore, know enough of the natural habits of the different fish to avoid injuring fisheries by the improvement of rivers; and he should try to improve the propagation of the useful species without unfairly interfering with other interests. The idea that river fishing was only for the pleasure of a few rich sportsmen was most misleading. Civilised countries would not expend large sums of money on fishery boards and inspectors if this were the only result. The salmon fishery of the Tay was worth £70,000 per annum, that of the Shannon probably £40,000, and of other rivers in proportion. The eel fishery alone of Lough Neagh and the lower Bann was worth at least £6,000 per annum. For the sake of fisheries, shallow margins to rivers should exist in some form. In salmon rivers, gravel shoals and shallow margins were the spawning grounds, which should always be covered with water not less than 4 inches deep. If the water subsided, so that the spawn and young fish were left high and dry, they were naturally destroyed. On the other hand, if the water was too deep, the ova might become sterilised. Therefore, in removing gravel shoals, shutting out shallow margins and encouraging accumulation thereon, and cutting off secondary channels, the reeds or nests of the salmon were lost. If no compensation were given, the fisheries would decrease greatly in commercial value. The velocity of the river, increased in times of flood, might disturb, or sweep away the spawn deposited in the gravel. Elvers also, on their way up from the sea in spring, always kept near the banks, to avoid a strong current, against which they were unable to swim. For these reasons, continuous training-walls, rising above the level of the dry-weather flow in the non-tidal parts of a river, as being carried out on the Rhone, were detrimental to the propagation of migratory *salmonidæ* and other useful fish. In the Rhone and other Mediterranean rivers, no salmon existed, owing to the temperature of the sea, so that the above remarks were not so strongly applicable to them. But for most rivers flowing into the Atlantic and Pacific Oceans, not nearer

the Equator than 40° latitude, it seemed doubtful whether the Mr. Willcocks works on the Rhone should be taken as an example.

Mr. J. V. WILFRID AMOR remarked that, in a modern work on Mr. Amor. geology a principle was very clearly explained—which had not been alluded to in the present Paper, nor in previous Papers on cognate subjects—in the following extract translated from the French:—"The accumulation of sediment (at the bottom of the sea) is helped by the property possessed by sea-water of retaining fine matter in suspension for a much shorter time than fresh water does. Thus, according to Mr. Sidell (quoted in Dana's 'Manual of Geology'), sea-water clears itself in fifteen times less time than river-water does; notwithstanding that, on account of its greater density, it causes bodies immersed in it to lose one-fortieth more of their weight. By experiments Mr. Sidell proves that precipitation which required ten to fourteen days to be completed in fresh water, took place in fourteen to eighteen hours in saline solutions."¹ In consequence of this principle, if a river of given volume of flow, bringing down a certain amount of alluvial matter in suspension, with a given velocity, discharged into a fresh-water lake; while another river, exactly similar, discharged into the sea, the result of the precipitating power of salt water would be that the alluvial matter would be transported to a fifteen times greater distance in the lake than in the sea. Anyone studying the two deltas without taking this principle into account, would be very much at a loss to explain their totally different characters. When a tidal estuary was full of salt water at high tide, the sediment brought down by a fresh-water stream discharging into it was almost at once deposited, not only on account of the reduced velocity, but much more perhaps on account of this precipitating power of salt water. This principle accounted to a great extent for the very beneficial effects of training-jetties at the mouths of rivers; because, by keeping the river-water separate from the sea-water for a greater length of time and space, they prevented the matter in suspension from being precipitated close to the mouth of the river.

He could testify from personal experience to the inconvenience caused by the want of training-jetties, as he had been stranded for a whole tide on a mud-flat at the mouth of the Mississippi in 1876, before the late Captain Eads had carried out his great work.

¹ "Traité de Géologie." M. Lapparent. 1882. Première partie. Livre deuxième. Section I, p. 169.

Mr. Amor. Also in 1872 he witnessed the painful anxiety of the crowd of spectators on the old pier at Portugalete, when in rough weather a ship in distress attempted to cross the bar of the Nervion. Both the inconvenience and the danger had now been done away with by training-jetties.

Mr. Corthell. Mr. E. L. CORTHELL said, with reference to the Paper on "The Training of Rivers," that the facts and general conclusions were important and valuable, and would be of great use to the engineer engaged on river and harbour works. There were, however, some few statements and conclusions which he felt obliged to controvert. It was assumed by Mr. Vernon-Harcourt that the Gulf of Mexico was a tideless sea, and that the Mississippi and other rivers entering it were tideless rivers. Comparatively speaking it might be possible to so consider it, as the mean range of the tides did not exceed 14 inches in any part of the Gulf of Mexico; but there were tides of much greater range occurring every month, and sometimes sufficient to produce a considerable current at ebb-tide, and they were all useful in assisting to make and maintain the channel between training-works. An examination of the tidal range given in his "History of the Mississippi Jetties" would afford an idea of the force of the tidal currents at times.¹ He had personal knowledge of the tidal conditions at several points on the Gulf of Mexico, notably at the mouths of the Mississippi, the Brazos River, the Aransas Pass, the Panuco River, near Tampico, Mexico, and the Coatzacoalcos River on the Isthmus of Tehuantepec. It might be assumed that there was an effective range of 2 feet for scouring the river-bed and the bars at the mouths of the rivers in the Gulf of Mexico. Nor must it be supposed that all the rivers emptying into the Gulf of Mexico were delta rivers. The Brazos, Panuco, and Coatzacoalcos discharged their waters into the sea through one mouth; and the bars in the sea had not advanced materially beyond the shoreline of the country. In fact at Coatzacoalcos, the record between 1871 and 1892 showed a recession of the sea-face of the bar.

Mr. Vernon-Harcourt, in forming his conclusions as to the effect of jetties at the mouths of rivers in the Gulf of Mexico, and elsewhere in comparatively tideless seas, had based them upon a misapprehension of the conditions, for he stated "dense matter, rolled along the bottom, soon comes to rest when the current is checked on emerging into the sea, and mainly forms

¹ "A History of the Jetties in the Mouth of the Mississippi River," E. L. Corthell, p. 227.

the bar which is invariably found in front of delta outlets." It Mr. Corthell was evident that he had assumed certain statements to be correct which were made in public documents prior to the construction of the jetties at the mouth of the Mississippi River. These statements were proved to be erroneous by Mr. J. B. Eads, the projector of these works. The discussion in the controversial literature of that time was summarized in the "History of the Mississippi Jetties" (pp. 24-49). It was there shown that very little material was rolled along the bed of the Mississippi River, in its lower reaches at least, and that the bar was formed almost entirely from the deposit of sediment held in suspension during the progress of the river towards the sea, which was dropped on account of the loss of velocity of the issuing current, spreading out fan-like over a semi-circular area. This sediment was dropped on the outer contour of the circular bar; the finer sediment being often carried by the diminished current far out to sea.

He must also take exception to the detailed statements and the chart which accompanied Mr. Vernon-Harcourt's Paper. This chart showed that the 30-foot channel was discontinuous; and while this was a fact, and the statement in the Paper was correct, yet the result as exhibited on the chart was temporary, and such conditions were only occasional, and not the normal conditions of the channel. The contract of Mr. Eads with the United States Government required that the channel should be made and maintained for twenty years, 26 feet deep and 200 feet wide at that depth, with a central depth of 30 feet without regard to width. With rare exceptions, during the fifteen years since this channel was obtained by the jetties and auxiliary works, the full size required had been maintained. It would be very difficult to maintain a channel by a natural current, the widths and depths of which should at all times comply with the arbitrary enactments of a law. This channel might be deeper than the law required, and slightly narrower; or it might be slightly shallower, and much wider. The dredging done from time to time was mainly for the purpose of making what was at all times a sufficiently large channel for navigation conform to the exact requirements of legal enactment. The normal conditions of the channel were shown in a chart in the report of the Chief of Engineers, United States Army, for 1893, where the 30-foot channel was continuous, and at least 100 feet wide. Mr. Vernon-Harcourt spoke of the necessity at one time of dredging the bar beyond the jetties, where there was only about 26½ feet of water. At the time, however, there was a 30-foot navigable channel, but not in the direct prolonga-

Mr. Corthell. tion of the jetties; and a channel was dredged for the purpose of opening a new channel in this direction. The condition of the bar then existing, which had made this dredging advisable, had appeared only once or twice during the last fifteen years, and was caused by "sand-waves," which occasionally during the flood season travelled down the river, past New Orleans, and dividing at the head of the passes into three divisions, went to the sea through the three main outlets of the river. During the passage of the sand-wave through the south pass, there was likely to be a temporary shoaling, which the natural forces dissipated as soon as the sand-wave passed into the gulf. The peculiarities of this condition were fully described in the reports of the Chief of Engineers, United States Army. It was expected by Mr. Eads, and by all who were connected with the works, that the delta would constantly advance into the gulf, and that the time would come, considerably remote however, when an extension of the jetties would be required. The fact that they had served their important purpose for fifteen years, with a probability that without any material extension of the works and with very little dredging, either in the jetty channel, or in the sea beyond it for a long period of years to come, was sufficient reason for having expended a moderate sum of money upon the construction and maintenance of the works. In order that there might be no misapprehension as to the amount of dredging required beyond the ends of the jetties in the gulf, the following extract was given from official records:—

DREDGING DONE BEYOND THE ENDS OF THE JETTIES.

1891.	1892.	1893.
January . . . 1 day	August . . . 4 days	January . . . 5 days.
August . . . 6 days	September . . 9 days	May 3 days.
October. . . . 1 day	December . . . 4 days	August . . . 2 days.

In a Paper which he was preparing for the Institution on the works constructed upon his plans, and under his charge, at the mouth of the Panuco River in Mexico, some of the important conditions and questions brought forward by Mr. Vernon-Harcourt in his Paper would be fully stated, and the general conclusions would be based upon twenty years of professional work along the shores of the Gulf of Mexico.

Mr. Luiggi. Mr. L. LUIGGI, Engineer-in-chief of the harbour works at Leghorn, observed that the two Papers under discussion were of the highest interest, and marked a distinct stage of progress in the

study of the physical features of rivers and estuaries; matters that Mr. Luiggi were formerly accounted for in a dubious or tentative manner being now, in most cases, explained on well-reasoned and clearly-established principles. There was, however, in both Papers one point not clearly defined, for it was practically assumed that the bars or shoals formed at river-mouths or estuaries were produced mainly by the materials deposited by the waters of the river itself. This was not precisely the case, as proved by many examples. There were channels of perfectly clear water, such as the Sile, near Venice, the Canale dei Regi Lagni, near Naples, and the Viareggio Canal, near Leghorn, the outlets of which were completely barred; also the channels between the Venetian lagoons and the sea, through which the sea-water was perfectly clear, were silted up to within 8 or 10 feet of the surface. On the other hand, there were many rivers heavily charged with solid matter, such as the Humber, the Severn, and the Thames, in none of whose estuaries were any serious obstructions found. It was, therefore, evident that the matter brought down by a river was not the only factor to be considered in the formation of the bar. The action of the waves in conveying material along the shore, and depositing it in any adjacent bay or inlet, had an important bearing upon the case. This effect was very distinctly traceable at Viareggio, where there were two jetties, between which a depth of 8 or 9 feet of water was maintained by constant dredging. Every time, however, that a storm came from the south-west, although the channel between the jetties might not be affected, the mouth was silted up to 5 or 6 feet.

Other phenomena tended to prove that the formation of a bar depended mainly upon the action of sea waves. The fresh water of a river flowing out into the sea formed, according to its force or velocity, a sort of barrier or liquid jetty, which acted almost like a solid jetty in stopping the travel of suspended matter along the shore. The matter thus arrested gradually accumulated against the liquid jetty, forming a kind of sandy groyne, and slowly deflected the outgoing current. This was very evident, for the rivers flowing to the North Sea through Germany and Flanders could not alter their northerly direction so long as they passed through mountainous districts; but as soon as they reached Holland or Belgium, where the rivers were free to flow into the sea in any direction, their outlets trended uniformly to the south-west, because the prevailing waves were from north-north-west. The more violent the waves, and the more perpendicularly they struck the shore near the outlet of a river, the greater was the

Mr. Luiggi. liability that a bar would form, as, for example, in the Mersey, the Tay and the reach of Sandy Hook. The contrary occurred if the outlet opened into a landlocked arm of the sea, as in the Clyde, the Severn and the Forth, or where it was protected by a headland washed almost tangentially by the waves, as in the Humber, the Maas and the Tagus. It was, therefore, clear that one of the chief factors in the silting up of estuaries was not the suspended matters in the waters of the river, but the action of the waves upon the foreshore.

In both the Papers the effect of the littoral current was much insisted upon. In the general conclusions, on p. 22 of the first Paper, it was stated: "If the sea-slope is very flat . . . and no littoral current exists, it is impossible by training-works of reasonable length to convey the deposit into deep water"; and further on: "The relative permanence of the depth obtained at the Sulina mouth, compared with the South Pass outlet of the Mississippi, shows that a littoral current exerting a powerful erosive action, combined with an alluvium comparatively moderate in volume and of low specific gravity, as in the case of the Danube, though with only a moderate dip of the sea-bottom in front, may prove more favourable to the maintenance of an improved depth than a considerably steeper sea-slope, accompanied by a feebler littoral current, and a larger volume of alluvium in proportion to the discharge of notably greater density, such as exist at the Mississippi outlet." From this it would result that the movement of materials in an estuary would depend essentially upon the slope of the sea-bottom and the density of the matter brought down by the river, and most of all upon the littoral current. Now, with the exception of a few places such as the Straits of Gibraltar, of Messina, and the Dardanelles, the littoral current in such tideless seas as the Mediterranean and the Black Sea had such an exceedingly small velocity that it was quite insufficient to affect even fine sand or silt. If it was borne in mind that the bottom velocity of the waves might be far in excess of that of the littoral current, it would be seen how important a part was played by the waves.

In the conclusions in the second Paper (p. 76), it was said: "By prolonging the training-walls by jetties out to a distance where the waves no longer affect the bottom, the depth of which varies with the exposure of the site and the height of the waves, the travel of the sand is stopped." Now, admitting that the result of prolonging the jetties to what was termed by Italian hydraulic engineers the neutral line, was to disperse the bar for

at least a certain period of time, it could not be conceded that it was sufficient to extend them to "where the waves no longer affect the bottom," because it was essential that the waves should affect the bottom. Otherwise the alluvium would simply be deposited at this point, and the useful effect of the jetties would be lost. If in such cases no bar could be formed, it was because the waves did affect the bottom with a prevalence of the return bottom wave, causing the alluvium to be carried out to greater depths in the sea. In connection with this, it was useful to refer to the studies of Parodi, Mati, and Cornaglia, which formed so perfect a complement to the earlier experience of English hydraulic engineers. The results of these researches might be thus expressed: (*a*) the undulatory movement of the sea generates an oscillating bottom wave, alternately towards and from the shore; (*b*) under the crest of a surface wave, the bottom wave moves toward the shore, while under the hollow it returns outwards; (*c*) the force of the bottom wave increases with the height of the surface wave, with the increased 'fetch' or distance from which the waves arrive, and with the depth of the sea at the point considered; (*d*) the energy of bottom waves may be considerable at great depths; (*e*) on a submerged rising bed, the force of the inward bottom wave is greater than that of the return wave; (*f*) matter upon the sea-bed is struck alternately from opposite directions; (*g*) the component of the weight of this matter parallel with the bottom slope may counterbalance the effect of the direct or inward bottom wave, or add to the effect of the return bottom wave, so that the force of the latter is practically in excess. Thus on a flat shore the waves have a tendency to wash the materials towards the shore, and to silt up the beach; while on a steep sea-bottom the return waves prevail, and the materials are carried out to greater depths, and the tendency is to erode or denude the beach; (*h*) the points at which the reciprocal effects of direct and return bottom waves, combined with the component of the specific weight of the alluvial matter, are counterbalanced, form the neutral line; (*i*) the greater the force of the waves, the flatter the slope of the sea-bed; and the less the specific weight of the suspended material, the deeper is the position of the neutral line. In the Mediterranean, this depth varies from 27 to 33 feet; (*j*) landward of the neutral line, the bottom waves carry the materials toward the shore; seaward they draw them to greater depths; (*k*) parallel with the beach, the materials travel in the same direction as the waves. With alternate sets of the waves they accordingly travel one way or the other; but their ultimate

Mr. Luiggi. direction is governed by that of the prevailing waves, which accords more or less with that of the prevailing winds.

It was clear that the proportionate effect of the direct bottom wave and of the return wave varied with the slope of the sea-bottom and the resultant direction of the gravitating force of the deposited or suspended material. The river or estuary current tended to diminish the force of the inward wave, and to augment that of the return wave, and so far helped to disperse towards the open sea the materials brought down the channel itself. The ebb and flow of the volume of tidal water which had to pass over a given point, also tended to neutralise the accumulation of material and to maintain a certain proportionate depth. Further, the ebb and flow were not always of equal duration. In many places the former occupied much longer time; and in such cases the solid matter being longer exposed to the return waves, the tendency was to scour this solid matter towards the open sea, while at the same time the neutral line was deflected nearer the shore. This necessarily facilitated the scouring work of the return bottom wave in maintaining the free waterway of the estuary.

The experience of Italian hydraulic engineers might be thus summed up: that the estuary or mouth of a river would keep itself free of all deposit if the neutral line passed within the estuary or mouth itself; and that under the contrary condition, there would be a continual tendency to silt up. In such cases no permanent improvement could be effected, except by constructing jetties on each side of the channel to extend beyond the neutral line. The Tees, the Tyne, and the Liffey were instances in point, and also the Venetian ports of Malamocco and Lido. In the latter, the scour obtained by extending the jetties into depths of 20 to 25 feet, or slightly beyond the neutral line, had increased the depth of the waterways from 8 or 9 feet to 25 feet, and in some places up to 30 and even 39 feet. The Sulina mouth of the Danube presented similar features, the neutral line being at about 20 feet below the mean sea-level; while in the South Pass of the Mississippi the corresponding depth was between 23 and 30 feet.

If the coast was in process of erosion there was naturally little tendency to the formation of a bar; but if the shore was silting up, the deposit would accumulate behind the windward jetty, and the neutral line would gradually be shifted seawards until it passed beyond the head of the jetty. The direct bottom wave then acquiring the preponderance, the channel itself would commence to silt up again unless the protective works were extended beyond the new position of the neutral line; but each

extension was effective only for a certain number of years, and required indefinite repetition, limited only by the enormous expenditure involved. Mr. Luiggi.

Some engineers designed windward jetties as solid masses, so as to prevent any material washing through from the shore into the trained channel; while others preferred to make them with sufficient voids to allow of the infiltration of silt to such an extent that the accumulation on the windward side was almost indefinitely retarded, while the scour in the channel itself was strong enough to prevent accumulation there. The choice of one system or the other must always depend upon the precise circumstances of the case. A good example of the so-called permeable system was the northern jetty of the port of Malamocco, formed of large random blocks of stone; and the sand was thus free to wash through the interstices, and formed a slight ledge inside the jetty, which the current carried out to sea. This infiltration and dispersion was maintained from 1868 to 1888, and during this period there was practically no dangerous accumulation of sand on the windward side. In the latter year, the external slope of the jetty was rendered impermeable by a facing of small stones; and since that period, the accumulation on the outer slope had rapidly increased, so that probably an extension of the jetty would soon become necessary.

Mr. H. T. SICCAMA noticed that Mr. Vernon-Harcourt alluded in his Paper to the difficulty experienced in rendering an upland river navigable during low states of the water-level, and at the same time capable of carrying down its maximum discharge during floods, as there were cases in which works intended for one condition might be injurious to the other. This difficulty could, under certain circumstances, be avoided by providing two river-beds, one more specially designed for low-levels, the other (for floods. Mr. Siccama.) This system had been applied, where possible, in the river improvements in the Netherlands on the lower reaches of the Rhine and the Maas. Both beds were sometimes contained between the same outer embankments; and at other times the flood-bed was carried over an independent line of country, which, during the summer and low water, was available for agriculture. This tract was merely kept clear of obstructions, and where crossed by high road-banks these were provided with numerous bridges. Where these so-called green rivers could not be provided, and where both summer and winter beds were between the same outer banks, the low-level bed meandered through the wider and higher flood-bed; and every reach and bend must

Mr. Siccama, in that case be specially considered. It was difficult to lay down hard-and-fast rules and formulas for the treatment of rivers, like recipes in a cookery book, although this had often been attempted. There were as many systems as there were rivers; what was a success on the Rhine might fail on the Danube, and excellent results were obtained on the Rhone by works impossible on the Mississippi. What was told them in the Paper under consideration made one wish for more information. The Rhone in particular, with its torrential floods and sometimes sudden subsidence, was a most interesting river to observe, and, from an engineering point of view, most attractive. Flowing, however, into a tideless sea, the mouth was not more complicated to deal with than the upland parts. It was where the tides had to be reckoned with that the problems become very intricate. Not only the quantities of water to be dealt with were larger, but the conditions were various and conflicting. The works required to obtain any effect were costly; and if found not to answer, as costly to alter or to remove. Works intended to improve the navigation through an estuary might have the effect of reclaiming land, and be fatal to the original object. Many instances of this might be adduced. For instance, in a case where the entrance was narrow, so as to obtain a greater scour over the bar in one spot, there the depth was increased; but two bars were formed, one outside and one inside the entrance, and the area enclosed gradually silted up, which again reduced the mass of tidal water oscillating in the enclosed space. It was often overlooked that in an estuary the deepest passes could only be maintained if the tidal wave could enter unchecked. The deepening was done by the flood-tide, as in most cases the flood slope of the tidal wave was steeper than the ebb slope. The greater its mass, the greater its living force and its maintained velocity, and the shorter the period of slack water during which suspended matter precipitated. If it was not feasible to give general rules for the maintenance of upland rivers, it was even more impossible to do so for estuaries. The only hint for guidance generally applicable, was not to obstruct the ingress or egress of the tidal wave, or to deflect suddenly its direction away from the estuary, or from its deepest channel. The velocity with which the flood entered an opening in the coast-line was not due solely to gravitation, but also to the living force heaped up in the wave. An instance in point was the new mouth of the Maas, where the old mouth, near Brielle, was the survival of the fittest pass, those to the north of it having gradually silted up. It was the free and untrammelled entrance

of the tide, as it came up from the south-west out of the English channel, which kept this pass open. Now, instead of assisting the natural forces in this channel, it was decided to reopen a channel on the site of those silted up ages ago, at right angles to the littoral currents. Of course the results did not answer expectations. The entrance jetties, instead of scooping up the incoming tide, and leading it inwards with its undiminished velocity, had their opening nearly at right angles to the direction of the flood current; and the power of the inflowing flood was due to gravitation principally, losing much of the living force of the wave sweeping past. Besides this, four varying conditions had to be dealt with during each tide:—(1) the flood rising at sea, with a current setting north and the river still ebbing; (2) flood at sea still rising with a northerly set, and running up easterly in the river; (3) ebb at sea with a southerly current, and a current still going up for a short time; and (4) ebb at sea with southerly current, and ebb in river. To these might be added the slacks of high and low water; and all these were again complicated by the differences in the strength and direction of the winds, and the quantities of upland waters discharged. The littoral currents, being nearly at right angles to the jetties, impinged on the obstructions, caused eddies, and formed pools near the jetty-heads. The flood current being the strongest, the deepest pools were found on the north sides of the jetty-heads; and the deepest water in the entrance, or the fairway, passed through the pool north of the jetty, and not being in the centre of the entrance, caused the fairway higher up to curve fantastically. It was only by continual and costly dredging that a sufficient depth could be maintained. The late Captain Blommendal of the Netherlands Royal Navy, and hydrographer-in-chief, repeatedly drew attention, while the new plans were discussed, to the dangerous experiment; but his very experienced advice was not listened to, owing to his differing in political opinions from the parliamentary promoters of the scheme. Now, however, those who had a practical interest in the matter had begun to see that an error had been committed. Some who had full local knowledge and experience averred that, should dredging be stopped, the cows would be able to walk across after a twelvemonth. At all events, the pass was not kept sufficiently deep by scour alone as had been expected. Estuary improvements being a hazardous undertaking, the prudence of the Mersey Dock and Harbour Board must be commended, as they were content to keep the required depth on the Mersey bar by the vast dredging operations which they were at

Mr. Siccama.

Mr. Siccama. present carrying out. With regard to Mr. Partiot's Paper, it might be said, that although precedent for the improvement of estuaries was seldom of great value, the success of the proposed works on the Seine mouth between Havre and Berville appeared problematical. They produced the impression that they would tend more to the reclaiming of land in the estuary than to the obtaining of a good tidal fairway. In the same way, if on the coast of Gascony, the flood came up from the south, a cut across the neck separating the inner basin from the sea at Arcachon might not give satisfaction; and the best course might be to assist the fittest surviving channel now running in a south-westerly direction. Working models of tides might give some information, in a general way, as to their action on solids of special conformation; but large allowances must be made for different or exaggerated dimensions, and the logical deductions from such observations must be accepted with caution. The temporary or trial-works spoken of were more trustworthy. Similar screens of wattling or fascines fixed against piles had frequently been used with satisfactory results by Captain Eads and his engineers on the South Pass, and by others on the higher reaches of the Mississippi near and above Memphis. The best way, however, to study an estuary was with the sounding-line in hand during all states of tide and weather.

Mr. Caland. Mr. P. CALAND was of opinion that the sectional area of rivers generally should be increased gradually downward, or funnel-shaped, so as to compensate for the gradually decreasing surface gradient, and the consequently diminishing velocity. Below the tidal limit this increase of sectional area should continue at a higher rate, so as not only to accommodate the ebb of the tidal water, but also the volume of discharge of upland water, arrested by the preceding flood-tide. Besides this, the river-mouth should be prolonged into the sea, by dams or jetties, to a point where the littoral currents were more sufficiently powerful to prevent the deposit of solid matter in front of the mouth. Where the quantity of solid matter brought down by the river was very great, the littoral currents might be deflected seaward, and it would then be necessary periodically to prolong the jetties. The sea, moreover, in many instances, tended to heap up materials along the coast-line, by which outlets might be closed; but if the discharge seawards could be maintained as the strongest influence, the heaping-up action of the sea could be counteracted. It was also very important, particularly on tidal rivers, to avoid straight reaches, as they provided no security for the fixity of the fairway.

A series of curves in succession appeared to be the most satisfactory. It was also highly important that the flood- and ebb-tide should follow the same deep-water channel, so as to avoid shoals between the two channels, which were always inconvenient for navigation. Changes in the river-bed should always be closely observed by continual sounding and velocity measurements. This was particularly required after high floods and ice, when unexpected and extensive deposits were liable to occur, requiring immediate removal by dredging to avoid inconvenience to the navigation.

With regard to Mr. Partiot's reference to the River Maas, he would observe that Fig. 12, Plate 4, was misleading, as the reclamation there shown was not due to the new works, for those areas were warped up ages ago in this formerly very wide estuary. Also the width from the mouth upwards and through the Scheur branch had been decreased regularly, so that the funnel-shape was maintained far inland. The depth in the new mouth was at present over 26 feet at low water, and about 33 feet at mean high water. He would refer to his book¹ on tidal rivers for a more exhaustive treatment of the subject under consideration.

Mr. G. VAN DIESEN submitted as his opinion, based on observation, that where a river's normal discharge was not increased in volume by confluent rivers, such a river did not require a progressive increase of width downwards for the maintenance or increase of its depth. Only below the point where other rivers discharged into it was a widening desirable, to avoid a dangerous rise of the river in times of considerable discharge.

Where a river flowed into a tideless sea, the decrease in the surface-gradient where it approached the coast would cause a diminution of velocity unless the water was prevented from escaping sideways. By preventing this lateral escape by maintaining a uniform width, the velocity of the current would be maintained, and consequently the depth. The depth at sea in front must determine the length of the jetties at the mouth; but the width between these should in no case be increased, so as to prevent the sediment forming shallows in the wider part.

Also for tidal rivers, he considered a seaward widening of the mouth objectionable, as it checked the conveyance of matter in suspension toward the deep sea, forming a bar, or in favourable cases a delta. For the improvement of a river flowing through

¹ "Études sur l'Effet des Marées dans la partie maritime des Fleuves," Paris, 1861, P. Caland.

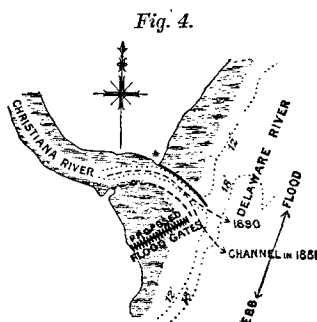
Mr. G. van Diesen. a delta, the several superfluous passes should be closed, and the undivided current directed through the pass most advantageously located. This was nothing else but abstracting the unnecessary width from the river. The widening of the mouth of a river towards the sea was often recommended for the free entrance of the flood-tide. Admitting that the entrance of large volumes of the flood-tide was favourable to a strong discharge during the ebb, it was not clear why a gradual narrowing of the river-bed inland should be considered to aid this, for a widening downward was a narrowing upwards; whereas, in his opinion, widening inland would be preferable and more favourable to the free ingress of tidal water, although there might be circumstances under which additional space for the flow of high tides or the discharge of upland waters might be desirable.

Mr. Stierle. Mr. A. STIERLE remarked that though there were no rivers nor estuaries in the district under the charge of General W. F. Smith, U.S. Army, of such magnitude as those cited in the Papers, what was lacking in size was amply made up in numbers. This district embraced all the rivers and harbours on the western shore of Delaware Bay, and on the eastern shore of Chesapeake Bay, as far north as the latitude of Wilmington, Delaware, and those on the Atlantic coast between Cape Henlopen and Cape Charles, the whole being known geographically as "the Peninsula;" which was indented by innumerable streams and bays, especially on the Chesapeake Bay side. The streams of the Chesapeake shore, from Cape Charles to the mouth of the Susquehanna River, had a remarkably uniform rise and fall of tide at their entrances, varying only a few tenths of a foot above and below the average of $2\frac{1}{2}$ feet; whereas those on the Delaware side had a rise of tide increasing steadily from 4 feet at Cape Henlopen to 6 feet at the mouth of Christiana River. Along the Atlantic coast, between the capes named, it varied between 3 and 4 feet. All the rivers on the Chesapeake Bay entered the bay through wide funnel-shaped estuaries, the smallest only of which were obstructed at the entrance by bars of littoral drift, caused by the currents being too feeble, and the volume of backwater too small to prevent their formation. The channels within the rivers were generally broad and deep as far as the tide flowed. The rivers in Delaware, however, were narrow, shallow, and tortuous, and without exception flowed into the bay through narrow outlets, and across a very flat, shoal foreshore, upon which the course of the channel could scarcely be traced, so that their entrances were navigable only at high tide. Whilst the streams on the Chesapeake side

were bordered but little with marshes, those in Delaware flowed Mr. Stierle. through wide expanses of marsh land, recent deposits of alluvium, overgrown with salt grass and reeds, and often covered by the waters of storm-tides. The formation and outline of the Delaware marshes clearly indicated that they occupied the place of former estuaries now almost entirely filled up, and that a greater movement of sedimentary matter, both during flood- and ebb-tide, took place in the Delaware Bay than in the Chesapeake Bay.

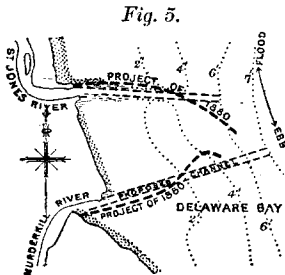
With one or two exceptions, the commerce on the rivers that had been improved by the United States Government in this district was comparatively small, and the improvements were made mainly for the purpose of creating a new branch of commerce, or of largely augmenting that which existed. As the dredged channels served the demands of a coastwise or a local trade, their dimensions were restricted, in proportion to the present and prospective commerce of the localities, to a depth of 6 to 15 feet at mean low tide, and to a bottom width of 60 to 300 feet. Since the question of cost largely entered into those improvements necessitating protective works in addition to dredging, they had to be limited in extent and carried on with great caution; and, in view of the small extent of commerce to be benefited, only a few of these rivers warranted any large outlay for their improvement.

The Christiana River in Delaware, *Fig. 4*, upon which the manufacturing and shipbuilding town of Wilmington was situated, was once a large arm of the Delaware River. Its tidal capacity was gradually much reduced by the reclamation of the adjacent low lands; and it was now a narrow stream about 14 miles long, the low-water widths in the lower section varying between 500 and 800 feet. In its present condition, the stream was able to maintain an average depth in the channel of 12 feet at low tide from the mouth to $3\frac{1}{2}$ miles above. This depth was periodically increased to 15 feet by dredging, the rise of the tide being 6 feet at the mouth and 2 feet at the head of the river. Much material, especially clay, was swept into it during floods and heavy rains from the high uplands to the north and west; and it also formed the receptacle for the drainage and sewerage of Wilmington, and, in consequence, was always charged with sediment. The prin-



Mr. Stierle. cipal obstruction to navigation was at the entrance, where a bar existed, which originally had $8\frac{1}{2}$ feet of water over it at low water. This bar, in conjunction with a certain portion of the river above it, had been dredged repeatedly to a depth of 12 feet previous to 1881, when Colonel W. Ludlow constructed a jetty, 1,800 feet long, on the north side of the entrance in a down-river direction to the 18-foot depth in the Delaware River, upon the ebb currents of which its outer end impinged at an angle of 50° . The jetty had deepened the water over the bar about 2 feet; but the channel had moved up against it, and was now very narrow at the outer end. No bar had formed outside the jetty, the configuration of the bottom being the same now as it was before the jetty was built. The contraction of the channel was due merely to an advance under the shelter of the jetty of the foreshore on the south side of the entrance. It had been suggested to partially close the funnel-shaped mouth of the river by another jetty on the south side, parallel to that on the north, leaving an opening of 500 feet at the outer end. General W. F. Smith had presented a design for the erection of a barrier consisting of a series of automatic flood-gates, in the place of a second jetty, which would open during flood-tide, and close during the ebb, thus obstructing as little as possible the influx of the tide, and concentrating the outgoing currents upon the narrow channel at the crest of the bar. The growing shipbuilding interests centring on the Christiana River, had of late years felt the necessity of an increase in the depth of the channel leading to the ship-yards; and a depth of 21 to 24 feet at low water was about to be sought by an extension of the improvement works upon this basis.

The outlets of the Murderkill and Saint Jones Rivers, *Fig. 5*, were about 3,000 feet apart, and emptied into Delaware Bay about 30 miles above Cape Henlopen. The tidal length of both rivers was originally 21 miles; the former, however, was now over 4 miles shorter, many of its long bends having been connected by "cut-offs." The "cut-offs" were made at first from 25 to 30 feet wide, but though some had been widened considerably by the river currents,



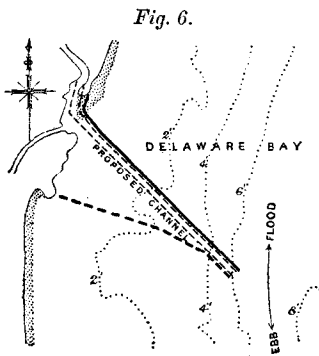
they were still much narrower than the river proper, which, at the narrowest point, was 90 feet wide. The many counter-currents, the eddies, and the friction thus created seriously inter-

ferred with the propagation of the tidal wave; and many of the Mr. Stierle.]
bends of the river that had been cut off were gradually filling up, causing a large reduction in the tidal capacity, the effect of which was particularly felt at the entrance. The river was in a very bad condition; shoals with only 3 feet of water at low tide were of frequent occurrence; and the water at the entrance was so shallow that the bottom was often bare at very low tides. The Saint Jones River, in which considerable dredging had been done during the past ten years, was a more powerful stream. Before its improvement, the rise of the tide was 4.1 feet at the mouth, and 1.2 foot at Dover, 21 miles above; whereas now the average rise was 4.8 feet, and 2.3 feet respectively. At the mouth of the Murderkill River, only recently put upon the list of navigable streams, the average rise of the tide was 3.8 feet, and at the town of Frederica, about 13 miles above, only 1.1 foot; whilst the low-water slope up the river was much broken, and the ebb current almost ceased to run when the flats at the entrance began to uncover, about three hours before low water in the bay.

The original plans of improvement for all the rivers in Delaware were, with one exception, devised between 1879 and 1882; and, as their condition was nearly alike, they comprised expensive works for improving their entrances. Chiefly for economical reasons, the channels inside the rivers were improved first, generally to the nearest town at the head of the navigation; but as these were being gradually completed, the question of improving the outlets across the flat foreshore, nearly a mile wide, ending abruptly in deep water, could no longer be postponed. In 1889 General Smith proposed the experiment of cutting a deep, straight channel across the flats at the mouth of the Saint Jones River, trained on each side by a bank formed with the material dredged from the cut; for the improvements within the river, just completed, were of little use unless the obstructions at the entrance were removed. The commerce of the river hardly warranted the construction of an expensive jetty; and, accordingly, the channel was dredged out at a cost of £1,500, to a sectional area slightly larger than the largest cross-section in the river. A cut, 60 feet wide and 6 feet below mean low water, was made along the axis of the proposed channel, from inside the river to the 6-foot depth in the bay, a distance of 4,800 feet; and along each side a smaller cut was made, 20 feet wide and only 3 feet deep, the berm thus left strengthening the sides of the channel against the weight of the banks. The excavated material, consisting for 500 feet from the shore of black, peaty, marsh mud, further out of sand, gravel,

Mr. Stierle. and boulders, mixed with some blue mud near the outer end, was deposited as far from the edge of the channel as the boom of the dredger could reach. Three years after, the depth along the centre of the channel was still 6 feet and more for 2,000 feet from the shore; the black mudbanks near the shore had settled to high-water level, and the gravel and sandbanks further out were visible only at low water. Beyond 2,600 feet from the shore, the banks, which had been made much lower there than those inshore, on account of the deeper water and corresponding decrease in the quantity of material excavated, had disappeared, and the cuts had been obliterated. Since then no material changes had taken place, and the shoals at the outer end would be dredged to 6 feet, all the depth the present navigation required. A similar channel was now being dredged at the mouth of the Murderkill River, converging towards the channel from the Saint Jones River, and both could be brought together to one outlet, if the growth of the local commerce should justify the construction of more durable protective works along the channels, as proposed in 1881 by Colonel Ludlow.

The Mispillion River, *Fig. 6*, entered Delaware Bay 18 miles

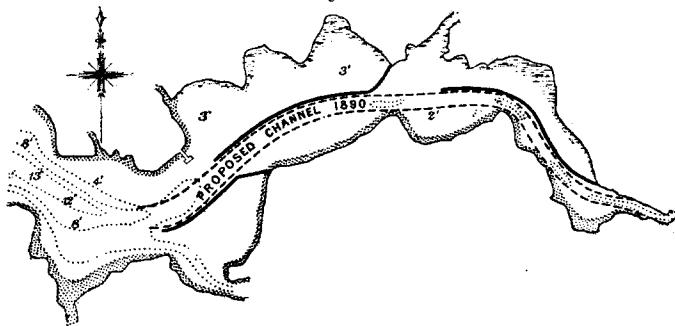


north of Cape Henlopen, and was 18 miles long; and it had been improved throughout by dredging a channel 40 feet wide and 6 feet deep across existing shoals. Its outlet also was barred by a flat muddy foreshore about a mile wide, and was formerly much further out in the bay, like the outlets of other Delaware rivers, as the shores of the bay were being worn away gradually by the waves. The receding of the shore had brought the

coast-line near a bend of the river parallel to it in direction, so that the mouth was bounded to the north by a narrow tongue of marsh, terminated by a long sandy hook with outlying shoals, round which the littoral currents and the waves carried considerable quantities of sand into the mouth of the river. The average rise of the tide was 4 feet. General Smith had proposed trying, in the first instance, to dredge a cut across the flats in a south-easterly direction, 150 feet wide and 6 feet deep at mean low water, protected along the north side by a bank of excavated material deposited by the dredger; but an attempt made a year ago, at the inner end of the cut, proved ineffectual, as the strong set of the

Mr. Stierle.
 tide and waves continually levelled down the banks and swept the excavated material back into the cuts. It was then decided to construct the protective works originally contemplated, consisting of a substantial jetty on the north side, and a dyke of mattresses and clay on the south side, commencing on the north side first, as far out as absolutely necessary; and 500 feet of a pile dyke had already been built.

The Manokin River, *Fig. 7*, was a tributary of Chesapeake Bay; and its estuary, 4 miles wide at the entrance, was 10 miles long, and had a fair depth in the channel, diminishing gradually from 42 to 9 feet, except within the upper 3 miles, where shallow mud-flats, with an average depth of 2·3 feet at low tide, extended from shore to shore. The river proper above the flats was 7 miles long, had a mean depth in the channel of 9·4 feet, and a width varying between 200 and 400 feet. It received only a

Fig. 7.

small quantity of fresh water, principally surface water from the adjoining lowlands. The average rise of tide in the estuary was 2·6 feet. The foot of the tidal wave arrived at the mouth of the river with a velocity of 31 feet per second, crossed the flats with a velocity of only 11 feet per second, and passed up the river with a velocity increased to 19 feet per second. Navigation was carried on by vessels of very light draught, and only during high water, the mud-flats effectually blocking the upper river at low tide. In 1890 General Smith made plans for the improvement of the flats by dredging or otherwise. In order to maintain, or, if possible, increase the present tidal capacity of the river, and in order to allow a free propagation of the tidal wave, it was calculated that a channel across the obstructions would need, at the lower terminus, a sectional area with a mean depth of 13·3 feet and a width of 235 feet, and at the upper limits of the flats, a depth

Mr. Stierle. of 8·9 feet and a width of 150 feet ; the intermediary cross-sections increasing from above towards the mouth according to the equation of a curve based upon the physical characteristics of the river. This theoretical channel was to be trained along the centre of the estuary, in curves of very large radii, by dykes on the concave sides of the channel raised to low-water level, composed of brush mattresses capped with the stiff blue mud excavated from the channel ; but the great cost, estimated at £59,850, compelled an abandonment of the plan. Instead, a channel 100 feet wide and 6 feet deep was being formed, the excavated material being deposited along the edge of the dredged channel to aid in training the currents. As a temporary make-shift, and considering the exposed locality, the improvements made so far were quite a success. The Manokin River was the only river on the Chesapeake side of the district where training-walls were considered absolutely necessary for a permanent improvement of the outlet. The outlets of other rivers requiring a greater navigable depth were simply improved by dredging. The dredged channels gave indications of shoaling only after a lapse of several years, and the required depth could be easily restored at small expense. The material excavated from the channels was taken away upon dumping-scows, and deposited in the indentations of the shore, or in deep water some distance off. One of the best illustrations in Chesapeake Bay of successful open artificial channels having no training-walls, were the extensive improvements made by Colonel W. P. Craighill, at the mouth of Patapsco River, forming the approaches to Baltimore Harbour. Of the many outlets and rivers rectified on the Chesapeake by the above-described method, only two had shown a somewhat greater tendency to shoal, after having been dredged, than others, viz., the entrance to Cambridge Harbour, Md., and the bar at the mouth of Onancock Creek, Va. The deterioration, in both cases, was caused by detritus drifting down the north shore with the prevailing winds ; and it might prove necessary to arrest the movement of this material by constructing short spur-dykes or groynes at a certain distance above these outlets.

Mr. Carey. Mr. A. E. CAREY considered that any accurate data as to artificial scour during the latter part of the ebb-tide on a tidal outlet would be of much interest. The system of artificial scour was much more common in French harbours than in those of this country. The danger of applying it was that, while excavating deep holes near the flushing reservoirs, the materials so moved settled again, shoaling the inner edge of the bar. He knew

instances in which its effects were thus detrimental rather than **Mr. Carey.** advantageous. In small tidal harbours, where funds were often very limited, the use of a harrow on the bar was sometimes a cheap expedient for gaining a slightly increased depth, and for preventing the bar from heaping up irregularly.

Mr. EYRIAUD DES VERGNES observed that the best methods for **Mr. Eyriaud des Vergnes.** regulating rivers in their fluvial portion appeared not to give rise at the present day to any difference of opinion. **Mr. Vernon-Harcourt's** Paper explained them very clearly, and confirmed them by interesting examples. Putting aside the proportion that should be maintained between the expenditure and the results, always a delicate question, their application presented no difficulty.

The problem was more complicated in the tidal portion of rivers, owing to the alternate changes in the direction of the current, and a consequent tendency for the ebb and flow to create distinct channels, each passing from one bank to the other. The object to be aimed at was to unite these two into a single channel, which would thus be most efficiently maintained by the alternating currents. But the modifications of the bed for bringing about this result should take into account previous works, often undertaken without reference to the whole river, should give facilities for the influx of the tide, and should allow for the special conditions due to the variations in the fresh-water discharge. It was often difficult to apply with precision the best general rules. He agreed with **Mr. Vernon-Harcourt** in considering that dipping dykes suitably directed were generally preferable to longitudinal training-walls, for regulating the channel in the tidal portion of a river, and that the sections should increase progressively seawards; but it appeared to him essential to consider these sections, rather than the actual width of the channel, in regard to these variations, bearing in mind that in sections of equal size the resistance to motion increased with the width. He would add that the necessity of a considerable amount of dredging, to produce fixity in the channel, must be admitted, concurrently with the construction of training-walls, if rapid results were desired.

The improvement of the mouth of the Adour was at the present time an object of special solicitude. The historical records of the changes of its outlet indicated that the natural, ancient outlet was near Cape Breton, 10 miles to the north of its present position, and that this was not due to a gradual diversion, since the mouths of all the rivers of that coast were driven southwards under the action of the littoral drift. It was a new outlet, therefore, that was

Mr. Eyriaud formed in 1578, and not an old outlet that was reopened. The criticism of Mr. Vernon-Harcourt on the original solid jetties, constructed at the close of the last century, appeared to be justified; it would certainly have been more advantageous to have made them converge, by placing them much further apart at their commencement, and carrying them out rapidly to a great depth. Considering, however, the period at which those jetties were constructed, it was not surprising that there had been misconceptions in these works, which had been pushed forward slowly in view of an immediate improvement which could not be maintained. At the present day the problem was better understood, and there were greater facilities now for obtaining large quantities of material than a hundred years ago; but though they would not now do the same as their predecessors, they were obliged to take existing works into account. He did not know from what source the figures indicating the hindrance to the influx of the flood-tide into the Adour had been derived; but it seemed certain that the tide rose as high at Bayonne as outside, and he, therefore, did not think that the flood-tide was checked as much as suggested; but he considered that the causes of its stoppage must be sought rather in the irregularities of the bed of the river above Bayonne. Some regulation works above had already caused the tide to flow $12\frac{1}{2}$ miles further up than formerly, and had consequently increased the tidal volume in the river, which method of improvement would be continued. The narrowing of the outlet was, indeed, mainly produced by the protrusion of the northern beach into the channel, which made the outlet-channel one-third narrower than the jetty channel. Since 1856 an endeavour had been made to direct the ebb current by means of open jetties standing on low rubble mounds, without paying any attention to the advance of the beach into the channel. It was, unfortunately, true that the results obtained were not commensurate with the expenditure; and though the direction of the outlet-channel had been rendered more stable, little increase in the minimum depth has been effected by the works over the bar beyond the jetties. The one definite, though small, advantage gained was that the lowest part of the bar was now in the navigable channel, whereas formerly it was outside this channel.

He considered that the essential defect of the present state of the outlet of the Adour consisted in the openings in the jetties, which allowed the sand to invade the channel, producing not merely projecting shoals inside inconvenient for navigation, but the bar itself as well. The Adour, indeed, brought no alluvium

to the sea, for its waters were clear, and any detritus from inland was arrested from above Bayonne; but the ebb-tide rolled seawards the sand coming in through the jetties, and deposited it very near their extremities, as the force of the ebb was partly lost in spreading right and left through the openings between the cylinders or iron piers. The Adour jetties seawards of the old solid jetties, exhibited four types of open work, namely, masonry viaducts, masonry columns with iron superstructure, iron viaducts with spans of $39\frac{1}{2}$ feet, and, lastly, cast-iron cylinders, $6\frac{1}{2}$ feet in diameter, and $16\frac{1}{2}$ feet apart centre to centre. The two first types partially kept back the beach, as their solid base was raised to the height of low water of neap-tides, and directed the ebb efficiently. The very open iron viaduct, with its rubble base levelled at zero, gave free passage to the waves, currents, and sand; but the portions of the jetties on cylinders were less disadvantageous, for though the rubble base was only raised on the average to $1\frac{1}{2}$ foot below zero, the cylinders left only three-fifths of the length open for the passage of the currents and sand. These open jetties, besides not affording sufficient shelter to vessels passing the jetty channel, gave rise to the principal shoals, one at the end of the masonry columns on the north side, caused by the sand coming in from the top of the beach, forming a projection extending sometimes 230 feet into the channel, and the other outside the jetties, constituting a bar projecting about 820 feet in front of the 5-metre ($16\frac{1}{2}$ feet) line of soundings. The ebb rarely lowered this bar more than 10 feet below zero, and the waves often raised it again to only $6\frac{1}{2}$ feet below this level; so that the depth over the bar at high water was seldom more than $16\frac{1}{2}$ feet at neaps and $20\frac{2}{3}$ feet at springs, which depths were frequently reduced to 13 feet and $17\frac{1}{2}$ feet respectively. Moreover, as the sea broke more violently on the bar in proportion to its height, vessels were obliged to allow for 2 feet of water at least under their keel to avoid chance of accident.

In his opinion the measures to be adopted for improving the condition of the outlet of the Adour should comprise closing the open jetties, to stop all inroad of sand, and to shelter the entrance channel, and also dredging the bar down to at least $16\frac{1}{2}$ feet below zero, which could subsequently be maintained by dredging away the moderate annual volume of material travelling from the north, and tending to come round the northern jetty. This was the aim of the investigations in progress; and as a trial had shown that the sand of the bar was very easily pumped up, a dredger suitably adapted to the local conditions would ensure the

Mr. Eyriaud des Vergnes. maintenance of a depth of $16\frac{1}{2}$ feet below zero in the entrance channel at a moderate annual outlay.

Mr. Evaristo de Churrucá. Mr. EVARISTO DE CHURRUCA desired to contribute some particulars of the improvements, effected under his direction, in the River Nervion, and on the bar at the mouth of that river.¹ The town of Bilbao was situated between 8 and 9 miles above the mouth of the River Nervion; and the tide extended about 5 furlongs higher up the river, this part of the Nervion being known as the tidal river, or Ria, of Bilbao. With a width varying from 160 feet in the upper to 525 feet in the lower part of the river, the volume of fresh water was very limited, in dry seasons not exceeding 140 cubic feet per second, or, with some small affluents between Bilbao and the sea, 250 cubic feet. The ordinary volume of river-water flowing to the sea was about 530 cubic feet per second, sometimes increased by floods to as much as 56,500 cubic feet; but these floods lasted for a very short time, so that the navigation of the port was almost entirely dependent on the tidal water. The rise of tide varied from a minimum of 4 feet to a maximum of 15 feet, the mean annual rise being 9 feet; and the volume of sea-water that now entered the harbour at ordinary high tide was about $10\frac{1}{2}$ million cubic yards, which increased to $15\frac{2}{3}$ million cubic yards during spring-tides.

The earliest notices in existence of the port of Bilbao concurred in describing its conditions as unsatisfactory. A document dated A.D. 1503 attributed the loss of many vessels every year to the dangerous nature of the bar, owing to its shallowness and instability, and also mentioned that ships were frequently detained in the harbour for long periods, because they could only leave the port at spring-tides, a condition of things which continued until a much more recent period. Early in the sixteenth century the mole at Portugaleta was commenced, on the western side of the river mouth, with the object of correcting the tendency which the waters of the Nervion had, in common with all the rivers on the same coast, to bear away westward along the shore as soon as they reached the sea, that being the direction of the prevalent winds. This wall was no doubt also intended to force a passage through the sandbank which formed the bar, but it was not extended sufficiently far out, and before long was partly destroyed by the sea, so that the advantages derived from it lasted only a short time. At a later date, a wall was built on the oppo-

¹ Minutes of Proceedings Inst. C.E., vols. lxxvi. p. 403; xeviii. p. 431; civ. p. 344; and cvii. p. 458.

site side of the harbour mouth, to control the shifting sands on the right bank, and prevent them from encumbering the channel; but this occasioned a gradual advance of the beach just beyond the wall, which again restored the tendency of the waters of the Nervion to follow the coast-line, and created a sinuous waterway dangerous to navigation. Some works were subsequently executed with the object of narrowing and deepening the navigable channel of the river. An estuary near its mouth, about 1,100 yards in width, and extending inland for nearly 2 miles, was left so nearly dry when the tide receded that only two narrow and tortuous watercourses remained, in which the depth was about 2 feet at low water. Between 1750 and 1760, this part of the harbour was improved by the construction of retaining-walls; but the plan was defective, for, instead of increasing the width of the channel as it approached the sea, the exit from the estuary was narrowed to 137 yards, whereas at the upper extremity it was given a width of 328 yards. While the depth at the narrow part was by this means increased at low tide to 13 feet, and that of the wider portion to 9 feet, the bar, with a constantly-shifting sandbank and only 2 or 3 feet depth of water, remained absolutely unaffected, so that in winter-time, even at high water, the navigation was greatly restricted. Vessels coming for iron ore usually arrived in ballast, drawing very little water, and could consequently enter the river without difficulty; but when laden with cargo, they could only leave the port at spring-tides, and, if the weather was unfavourable, were often obliged to wait for weeks or months before they could venture across the bar. On one occasion, for example, during the winter of 1875-76, although the largest vessels at that time drew only 13 feet of water, they were all detained in the river for three months and a-half. The harbour remained in this condition until the construction of several railways, and the rapidly-increasing importance of the shipments of iron ore, rendered great improvements in the river and on the bar indispensable. Accordingly, in 1878, he presented a report with plans for the improvement of the river, in accordance with which the works had since been executed.

Besides lowering the bar, the whole of the river required dredging, especially in the upper portion near Bilbao, where a great accumulation of stones and gravel obstructed the navigation; abrupt curves in the channel needed also to be corrected; and the regulation of the river, commenced during the last century, required to be improved and completed. To deepen the water on

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the bar was the most difficult part of the undertaking. The insignificant volume of river-water, and the limited extent of surface over which the tidal waters spread themselves within the river, occasioned an unusually sluggish current; and it was expedient to examine very carefully how, under these circumstances, the flow of the tide at the mouth of the river could be most advantageously brought to bear upon the bank of sand and alluvial deposits which formed the bar, in order to create a permanent and deeper channel through it than the then existing shallow, shifting, and tortuous passage. The flow of the rising tide outside the harbour was N.W. to S.E., and its velocity only $1\frac{3}{4}$ foot per second, or about one knot per hour. Part of the incoming water entered the river in a direct line with accelerated motion; but the larger part, striking first against the sandy beach on either side of it, especially on the broad expanse called Las Arenas, on the eastern side, stirred up the loose sand, and, forming separate currents parallel to the beach, carried the sand into the harbour and about 2 miles up the river, until, on the turn of the tide, it was brought back again. The maximum speed of the flood-tide at springs, at the mouth of the river, was only 6 feet per second, or about 4 miles per hour, and if compared with the velocity of the tide entering the River Seine, which was from 12 to 18 miles per hour, was a very moderate current to work with. The flood waters of the River Nervion brought down large quantities of rolling stones, gravel, sand, and mud, which had also to be provided against. The stones and gravel were usually deposited within 2 miles of Bilbao, the finer sand reaching a distance of about 4 miles; while the particles of mud were carried by the water to the mouth of the river, and together with those brought down by the Cadagna river and other minor affluents of the Nervion, generally sank to the bottom on the turn of the rising tide. It did not appear, therefore, that the alluvial river deposits affected the bar; and, moreover, it was ascertained by soundings that this was composed of sea-sand, precisely resembling the sands which formed the beach at Las Arenas and at Portugalete, which consisted, in about equal proportions, of fine silicious grains and pulverized marine shells. He came to the conclusion that the shallowness of the bar was mainly due to the shifting to and fro of the sea-sands by the ebb and flow of the tide, and by the subsidiary currents running parallel to the extensive sandy beach of Las Arenas; and he therefore advised the prolongation of the western mole at Portugalete for 875 yards, extending it beyond the bar to a depth

of 20 feet at low-water spring-tides. The tendency of the ebbing water to flow westward along the shore would thus be corrected, and it would be directed against the bar itself. The mole, if extended in a straight line, would have run due N.W., but by giving it a very slight northerly curve with a radius of 3,280 yards, several advantages were foreseen: (1) The westward tendency of the ebbing current would deepen the new channel close to this sea wall; (2) Without making the passage into the harbour in any way more inconvenient than before, additional protection against the swell of the open sea coming from the N.W. would be afforded to the entrance channel, with advantage to the vessels passing in or out, and an increased depth in the bed of the new channel would be maintained; (3) It was foreseen that the construction of this wall would affect the deposits of sand on the right bank, and probably cause them to advance with it, but the more northerly trend of the wall at the extremity would prevent this sand from settling transversely to the new channel, and it was hoped that it would take a direction parallel to the wall, and thus improve, rather than encumber, the waterway—which was precisely what had happened. A tongue of sandbank had been formed, about 160 yards in length, but its width was so insignificant that in boisterous weather it was frequently carried away by the waves. He, moreover, considered that any prolongation of the existing wall on the side of Las Arenas would probably have the effect of creating a prejudicial reflex action, which decided him to leave the channel open on that side. In the above-mentioned report it was pointed out that in order to complete the security of the port, and to remove all danger to the navigation in tempestuous weather, it would be necessary to protect the outer harbour by breakwaters; but their cost, estimated at £800,000, was far in excess of the funds at the disposal of the Board in 1878.

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The works were commenced in 1881, and a due regard to economy, combined with rapidity of execution, determined the mode of construction. It had been ascertained by soundings, to a depth of 26 feet below low water, that no rock foundation could be reached; and the work was, therefore, proceeded with as follows: (1) A pier of wrought-iron upon screw piles was first erected to serve as an auxiliary scaffolding for a foundation of stones up to low-water level, and for a concrete superstructure reaching to high-water mark; (2) the foundation was formed of loose stone thrown into the sea between the piles, and on either side of them, up to the level of low water, and allowed to settle into place before commencing the superstructure. The outer end of this stone bed

Mr. Evaristo de Churrua. was protected by artificial blocks weighing 27 tons; (3) a solid body of concrete was next constructed on this foundation, reaching a height of $13\frac{3}{4}$ feet above low-water spring-tides.

The foundation bed was allowed to settle during the winter of 1881-82; and by May, 1882, when it had attained a length of 984 feet and the concrete superstructure 295 feet, the bar had already been so favourably affected that several vessels drawing 17 feet of water were able to issue from the port; and the improvement steadily continued as fast as the work proceeded. Some tempestuous weather in the following October occasioned strong currents which increased the depth on the bar from the previous 3 feet at low water to 11 feet; but it also somewhat damaged the extremity of the iron pier, which determined the Board to alter the construction of the then uncompleted 656 feet of wall, and to make the remainder of the pier in a more substantial manner. The result obtained by the construction of this wall was even better than had been anticipated; for whereas the report said that the depth on the bar would be increased to $11\frac{1}{2}$ feet at low-water spring-tides, it had now attained a depth of $14\frac{3}{4}$ feet; and a permanent fixed channel had been created with a width of about 230 feet. At all seasons, vessels drawing 18 feet could now enter at any tide, and even vessels of 22 feet draught during spring-tides. Within the river itself, the abrupt curves which before existed had been removed; the regulation of the river up to the town of Bilbao had been improved and completed; and two large basins with good anchorage for ships had been created. The breadth of the channel at the Arenal bridge of Bilbao was 197 feet; and it widened gradually until, at 8 miles below, between the moles of Portugaleta and Las Arenas, it attained a width of 525 feet, with occasionally an increased breadth given at points where vessels congregated. The river had been extensively dredged, and had now, throughout its whole length, a minimum depth of 13 feet at low water of spring-tides, so that ships of 3,000 tons, drawing 20 feet, could reach the quay-walls of Bilbao. The whole body of water which entered with the tide left it again with the ebb, the low-water line being practically level from the sea to the town; while at high water of spring-tides, it was 1 foot 7 inches higher at Bilbao than at the mouth of the river.

The total cost of the works executed in the river and in the improvement of the bar, omitting the subsidiary expenditure on electric lighting, buoys, cranes, &c., and on maintenance, had amounted approximately to £467,590, namely, extension of the

jetty, £115,890, and regulation and dredging of the river, Mr. Evaristo de Churruca. £351,700.

In his inaugural address as President of the Institution of Civil Engineers, in November, 1886, Mr. Edward Woods, after describing the mineral railways at Bilbao, and the works of improvement on the bar and in the river, said that "owing to the facilities now given, Bilbao ore, which in 1872 realised 35s. per ton, delivered at our ports (one-half the cost representing freights), is at the present time landed at South Wales (where the import is 1,000,000 tons per annum) at a cost of 10s. to 10s. 6d. per ton, including freight, which does not now exceed 4s. per ton."¹ This statement justified Mr. Churruca in claiming that at least 7s. of the reduction in the freights might be attributed to the works in the river and on the bar. The reduction had been in force for the last eleven years, during which time 48,756,000 tons of imports and exports had been registered, from which it appeared that the advantages derived by commerce during those eleven years from the improved navigation had equalled forty-four times the whole cost of the works. During the years 1878-79, the imports to Bilbao amounted to 144,977 tons, and the exports to 1,195,422 tons, making a total of 1,340,399 tons; whereas during the year 1892-93, the imports amounted to 759,864 tons, and the exports to 4,368,967 tons, or a total of 5,128,831 tons. This notable increase had resulted in a proportionate increase in the funds of the Board of Works, and had enabled them to commence the construction of the breakwater which would enclose and shelter the outer harbour and convert it into an excellent harbour of refuge. The western breakwater, starting at a point about 1 mile from the end of the new Portugalete sea-wall, would be 1,586 yards, and the breakwater on the eastern side of the harbour, 1,173 yards in length. Together, they would completely protect the port from the direct action of the ocean waves, while allowing easy entrance to it for ships. The area enclosed by these breakwaters was 709 acres, of which 507 acres would have a depth of water at low water of spring-tides of between 16½ feet and 50 feet. The estimate of cost of the western breakwater was £890,300, and of the other £344,130, or a total of £1,234,430. The western breakwater was commenced in 1889, and the greater part of its foundation-bed was now completed up to the level of low water. It had already a considerable effect in diminishing the surf on the bar. On the eastern side, the execution of the work was

¹ Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 21.

Mr. Evaristo de Churruca commenced in March of the present year. Both would probably be completed by the year 1900; and Bilbao would then be the finest port in the Bay of Biscay.

Mr. Shoobred. Mr. J. N. SHOOLBRED wished to make a few remarks on that part of both Papers which referred to the training of tidal rivers. He was well acquainted with the outlets of the Adour and of the Nervion, having surveyed the estuary bay of the latter for the formation of a harbour rather more than thirty years ago on behalf of the late Mr. C. B. Vignoles. He could not agree with Mr. Vernon-Harcourt as to the close analogy which he considered existed in the conditions in which the outlets of the two rivers were placed. The Adour discharged direct into the open Bay of Biscay, and the mouth was exposed to the full force of westerly and north-westerly gales; while the Nervion emptied into a cliff-protected bay, which, though small, sheltered the mouth altogether from westerly gales and also from the full force of many north-westerly ones. The high cliffs on the western or Santurce side, under which a comparatively deep-water channel lay, afforded much more protection than did those on the eastern or Algorta side, where the water was shallower and more exposed to north-westerly gales. The eastern breakwater, not yet made, was, in his opinion, of small importance in comparison to the western one, already constructed. Moreover, he considered that the former should not be in the position indicated on Fig. 17, Plate 2, but further northward, at the projecting point beyond Algorta, so placed as to be outside the western breakwater, and thus protecting the mouth of the harbour from the broken water on the eastern shore. He was glad to note the considerable improvements which had taken place of recent years in the navigable depth of the river itself up to Bilbao—a matter of much importance, not merely to that town, but also to the large trade in iron and coal which was carried on between this country and that part of Spain.

Respecting the distinction which Mr. Partiot drew between the estuaries of the Gironde and the Seine, with both of which he (Mr. Shoobred) was also acquainted, he could not agree with Mr. Partiot in first classing the former river as having a “narrow-neck” entrance (referring to the contraction between Royan and the Pointe de Grave), and then denying that in the Seine, which he classed as having a “funnel-shaped” entrance, there was any similar narrowing in. Surely the contraction on the Seine between Tancarville and Quillebeuf had quite as marked, and a similar effect, upon the tidal flow in that river, as the one between Royan

and the Pointe de Grave had upon that of the Gironde. He joined with both Mr. Vernon-Harcourt and Mr. Partiot in deploring the large amount of accumulations which had for some years back taken place in the lower part of the tidal portion of the River Seine, and more recently in the outer estuary, especially in the immediate vicinity of the Port of Havre. The accumulations in the estuary during the last fifty years amounted to nearly 500,000,000 cubic yards, and they had caused an abstraction, during spring-tides, of over 250,000,000 cubic yards of tidal water, the largest portion of this damage having occurred during the last twenty years. So seriously, in fact, was the present entrance to the Port of Havre threatened that a proposal had been submitted to, and had been passed by the French legislature, to create a new and more northerly approach to that port by means of an outer harbour, having an area of somewhat over 600 acres, and with a northern and a southern entrance, at a cost of about £3,000,000. The breakwaters would be constructed of large blocks of concrete in two sizes, weighing about 60 tons and 90 tons respectively, built up vertically on inclined beds on a rocky foundation. Much of the success, however, of this attempt to provide a permanent deep-water entrance to the Port of Havre would, it was admitted, depend upon the form which might be given to the extensions through the estuary of the training-walls from Berville to the open sea. Of the many suggestions, the most reasonable (though it did not find favour with Mr. Partiot) seemed to be the "trumpet-mouthed" one, whereby the northern lip of the seaward end would include the approaches to Havre, and its southern edge would rest upon the Ratier shoal, the narrowed neck inland joining, on both sides of the river, the existing termination of the training-walls near Berville.

Mr. W. SMITH, of Aberdeen, observed that the successful treatment of navigable estuaries for their improvement and conservation was purely practical. At Aberdeen, although the natural tidal basin formerly existing at the mouth of the River Dee could hardly be classed as an estuary, being only 2 miles long by half a mile wide, the low-water course of the river through the basin was diverted southward, in 1869-70, with a view to increase the upland and tidal currents over the bar at the harbour entrance. The whole of the basin was filled up, except an area of 152 acres which was deepened to form docks and tidal harbours. The diversion of the River Dee had no effect, however, as a scouring agency, although the tidal capacity of the harbours and docks exceeded that of the former tidal marsh. Since the River Dee had been diverted, the

Mr. Shoobred.

Mr. Smith.

Mr. Smith. navigation channel, tidal harbour, and docks had been deepened by dredging out 6,282,883 tons, of which 3,179,069 tons were silt washed in by the sea and rolled down its bed by the River Dee, and 3,103,814 tons consisted of boulder clay. The minimum depth on the bar, which was formerly 20 feet at high water of spring-tides, was now 25 feet, the shallowest part of the channel being over a reef of rock about 200 yards within the bar. An important result of the continued removal of the silt by dredging as it was refilled on the site of the bar, by the waves moving the sand inward from the bay immediately outside the harbour entrance, was the deepening of that portion of the bay by wave scour. Most of the layer of sand formerly overlying the boulder clay to a depth of 3 to 5 feet, had been swept into the navigation channel, and now, instead of a bar of fine sea-sand to be dredged to a depth of 4 or 5 feet every summer, there were thin patches of sand with large boulders on the top. Unfortunately the boulders were more easily swept into the harbour now that they were uncovered in the bay than the sand had been. Owing to the friction of the extensive surface of the particles of fine sand rubbing upon each other under a heavy weight of water, the mass of sand presented a much greater frictional resistance to movement along the bottom by waves than large stones. The sand brought down by the River Dee was rolled into a deep basin in the inner part of the navigation channel, from whence it was easily lifted by the dredger and sent out to sea in hoppers. The direction further improvement must now take at Aberdeen harbour was deepening the channel by rock-cutting and dredging, and protecting it from the entrance of boulders and silt by additional sea-works.

The greatest action of waves upon the sea-bottom at Aberdeen appeared to occur in depths of between 2 and 6 fathoms. The action was consolidated by the influence of the depth, or head of water, upon the water at the bottom, the difference of head due to the height of the wave being transmitted most favourably at these depths. Wave scour on the sea-bottom occurred, however, at much greater depths than 6 fathoms, depending upon the height of the waves. As the depths shoaled below 2 fathoms, the power of the waves was dissipated in churning as breakers, the head of pressure at 2 fathoms or more being required to keep the water unbroken. In the expression he had formerly given¹ for the scouring power of a wave, $p = q \left(wd + w \frac{v^2}{2g} \right) 6a^2$, where q was the

¹ Minutes of Proceedings Inst. C.E., vol. c. p. 202.

viscosity, w the unit weight of water, d the depth from crest to Mr. Smith. trough, and a the length of side of sand or stone cube, q might be regarded as the coefficient of the action of the unbroken wave upon the materials of the bottom, the remaining proportion of the power of the wave being spent on continuing the movement of the wave to the shore, and in cresting and breakers. Thus the continuance of the movement of a wave over a shoal, at a uniform depth just sufficient to keep the wave from cresting or breaking, would result in the whole of the power of the wave being spent on the movement of the materials of the bottom. The principal banks in the great estuaries of the British Coast might have been formed while the mean level of the sea was higher by about 12 feet all over Western Europe, which historically would probably be prior to the time when the Roman harbour of Ostia fell into decay 1,300 years ago. The retirement of the sea from the land through the variation of glaciation at the poles, as demonstrated by Adhemar and Croll, would thus account for the present cessation of natural forces in the movement of banks and estuaries. The formation of the Mississippi delta from the average yearly amount of alluvium stated, 300 million cubic yards, must have occupied a period of 355,000 years under the most favourable circumstances, that is, while the greater part of the area was still submerged.

Mr. L. FRANZIUS remarked, in reference to Mr. Vernon-Harcourt's Mr. Franzius. statement as to the increase of the tidal volume passing Bremerhaven, that the actual volume had, up to the present time, shown very little variation, and that the theoretical increment quoted would require corresponding modification. On the other hand, the volume at Farge (about half-way between Bremen and Bremerhaven) had increased from 514 cubic yards to 810 cubic yards per second. The tonnage and draught of vessels arriving at Bremen had considerably increased since the execution of the training-works¹. During the year 1893 the number of sea-going vessels traversing the Weser as far as Bremen was thirteen hundred and seventeen; of these, four hundred and eleven had a draught exceeding 14 feet, eighty-five more than $15\frac{1}{2}$ feet, and fourteen between 16 feet and $18\frac{1}{2}$ feet. During the month of April, 1894, the number of vessels drawing more than 13 feet was forty-two, two of these having a draught of $16\frac{1}{2}$ feet.

¹ Mr. Franzius has presented to the Library of the Institution, Part ii. of "Fortschritte der Ingenieurwissenschaften," Group 2, containing (pp. 48 to 60) an account of the training-works carried out on the Weser, and the harbour works at Bremen and Bremerhaven (pp. 62 to 73).

Mr. Wells. Mr. L. B. WELLS observed that few questions had given rise to so much controversy among engineers of late as the training of estuaries, and there was no subject at the present time better deserving the attention of the members of the Institution. In a Board of Trade return of 1890, it was shown that whereas in 1840 the tonnage of vessels entered and cleared from ports in the United Kingdom was 9,439,667 tons, in 1889 this tonnage reached 71,889,895 tons, an increase of nearly 800 per cent. in fifty years. As the numbers given referred to register tons, and the tonnage of steamers, which carried much more on their register than sailing vessels, had increased from 791,555 tons to 58,764,200 tons in that period, the bulk of cargo handled was much greater than the figures of 1889 denoted. The increase in the size of vessels demanded deep water and improved channels; and it was necessary to provide accommodation to meet the present requirements and further expansion of this enormous traffic: to supply this ports and estuaries must be improved. Much had been done during the latter half of the century, since the Tidal Harbours Commissioners reported; but he considered that much more would have been accomplished for the improvement of estuaries by training-walls had the Commissioners worded their report more circumspectly. They condemned in unqualified terms all reclamation, because the tidal area would be reduced; and a reduction of tidal area was held to be necessarily followed by damage to the navigable channel. Training usually caused accretion, at any rate in some portion of an estuary; and very frequently harbours existed on the lower portion, with monetary interests antagonistic to the development of ports higher up, and this dictum of the Commissioners had been often used with effect to prevent any works being undertaken for the improvement of estuaries. Where the chief authority and population were situated away from the sea, estuaries were improved by training and dredging, as the Clyde, the Tyne, and the Tees, which had resulted in enormous benefits to the communities. By training a channel a maximum service was obtained from the momentum of the water passing in and out of it, which momentum was necessarily lessened when sandbanks were being moved and new channels formed. The dock and river-walls on both sides of the Mersey at Liverpool had stereotyped a channel for a considerable distance, and the effect was felt far beyond the limits of the walls, and had rendered the lie of the channel, both northwards in the direction of the bar, and southwards in the direction of the Upper Mersey, much more stable. In the upper estuary this had been followed by a gradual improvement in the

navigable depth, as evidenced by the larger vessels trading to the Upper Mersey ports from decade to decade. For a distance of about 4 miles, the outer embankment of the Manchester Ship-Canal was almost wholly in the estuary, from just above Runcorn to below the Weaver mouth, and, like the walls on the Liverpool and Birkenhead sides of the Mersey, had cut off certain baylets into which the tide used to flow and the main channel frequently wandered. Since the completion of this embankment, the direction of the channel opposite Runcorn had altered but little; a sufficient time, however, had not yet elapsed to test the permanent effect. Information in his possession showed that the low-water level had been lowered at Runcorn bridge, and had never previously been known to fall so low at Weston Point as it had done this year; this was the best evidence of an improvement in the navigable depth. The increase in the low-water section at the bar, which was now being dredged so successfully by the Mersey Dock Board, had probably helped to effect this; but, in his opinion, the modified training had materially assisted in improving the channel. It was noticeable that the improvement had taken place during a period when the rivers had been unusually free from heavy land floods, and when there was a newly-made outlet for the Mersey water at Eastham, and any change was, therefore, attributable to tidal action. In times gone by, and also in recent years, marshes and foreshores had been reclaimed, and the tide excluded over large areas of the Mersey estuary. During the construction of the Manchester Ship-Canal, and since its completion, large volumes of tidal water had been displaced; and since, notwithstanding this, the channel had improved, it was fair to assume that these alterations were beneficial.

Careful records of works carried out in estuaries and their effect on the channels, bar, and tides, were much to be desired. The late Captain Calver, R.N., surveyed many of the harbours and estuaries on the coasts of England, both before and after training-works had been commenced, and gave the results of his experience in his book on Tidal Rivers, which engineers connected with estuary works might study with advantage.

Mr. BENDON B. STONEY observed that he was frequently struck with the manner in which the past generation of engineers, when engaged in training rivers, somewhat slavishly followed the curves which nature delighted in, in place of boldly making long straight reaches, even at the expense of apparently opposing nature, but really by controlling her. Their idea, and it seemed to prevail still to a certain degree, was apparently that long sweeping

Mr. Wells.

Mr. Stoney.

Mr. Stoney. curves were more easily maintained than straight reaches; and some of the rivers described in the Papers illustrated this tendency. In the case of the River Moy, in the west of Ireland, he had succeeded in forming a trained navigable channel which, when the works were completed, would extend in one straight line for a length of nearly 5 miles—from Ballina quay to a short distance inside the bar. The natural channel of the Moy at low water was very tortuous, and apt to shift from side to side of the river and estuary, with frequent shoals that greatly impeded navigation; but the improved portions of the channel were now straight, and had from 3 to 4 feet greater depth than formerly. This was due to the current being confined within nearly parallel walls, but which gradually diverged as they approached the mouth of the river, and which extended to a little over half-tide level. The revenue of the Moy Commissioners did not admit of expenditure on dredging; and the principal cutting action took place when the ebb-tide was augmented by a river-flood from heavy rains. In other river improvements that he had been connected with, the navigation channel had been permanently injured by the original designers stereotyping the curves and bends of the natural channel.

Though the special conditions of every river necessarily required special treatment, yet a few general principles might be laid down which would seldom require much alteration. (1) Bends should be avoided whenever practicable, and nature's tendency to curve or meander from side to side of the river-bed controlled, sometimes even at the risk of not immediately gaining quite as deep a channel as nature had already provided in the curves. (2) Operations should be commenced from the higher end of any one series of improvements, for each modification of a river channel, though it might perhaps have little or no appreciable effect on portions higher up, almost invariably had far-reaching effects on the river lower down; and the influence of such improvements on the lower reaches should, whenever practicable, be allowed time to develop, and their consequences should be carefully studied before commencing operations farther down. (3) Training-walls in tidal rivers and in tidal estuaries should be made no higher than was absolutely necessary, lest serious silting should take place behind them, and the tidal capacity of the river or estuary be reduced to such an extent as injuriously to diminish the scour lower down or on the bar. Where funds admitted of dredging on a large scale, the height of training-walls might often be greatly reduced, and, in fact, either omitted as in the Liffey outlet, or only made just high enough to define the navigable

channel and prevent it wandering from its proper direction. If Mr. Stoney. this course had been adopted in the estuary above Liverpool, and if the Manchester Ship-Canal had been brought through the Runcorn sands by means of a dredged channel bordered by low stone-protected slopes, this stone fencing possibly not reaching as high as low water, there would doubtless have resulted a great enlargement of the tidal capacity of the estuary, by the lowering of the sands for wide distances on either side of the excavated channel, as the sands would, under the influence of frets, tidal currents, waves, wind, and wash of passing steamers, gravitate into the deeper channel, to be thence removed by dredging or by sand-pumps, now so successfully employed by Mr. Lyster on the Mersey bar. The width between the training-walls of rivers, when funds were not available for dredging, and when, therefore, the improvement and maintenance of the navigable channel depended on scour, required very careful consideration, as the channel must be wide enough for safe navigation, and at the same time the walls must be close enough together to give sufficient velocity to cut away shoals when there were freshets in the river, and at other times to maintain the normal depth. Probably $2\frac{1}{2}$ to $3\frac{1}{2}$ miles an hour was the least velocity that would appreciably cut away sandbanks. In tidal rivers and estuaries, and when the land water was of small account, the maximum cutting effect of ebb-tides was confined to spring-tides, and generally occurred about the third quarter of ebb, as the current was then, for the most part, confined within the borders of the trained channel, and the volume of water was still large, and its velocity at its maximum on account of the gradient of the falling tide having its steepest slope at about half-ebb. In the last quarter of ebb, not only was the velocity much reduced, but the volume of moving water was diminished; and this materially affected its capacity for carrying sand.

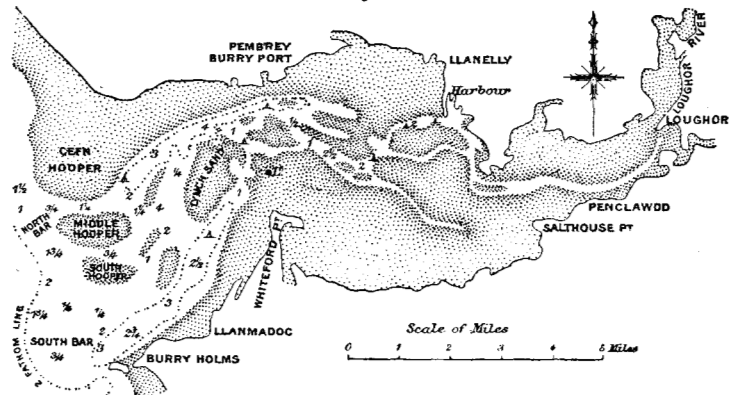
The Authors of the two Papers differed widely in their views of the best mode of improving the Seine estuary. Mr. Vernon-Harcourt advocated a trumpet-shaped outlet, while Mr. Partiot proposed restricting its outlet to a narrow neck. The latter method had in some cases been most useful for deepening bars and protecting the estuary inside from wave-action; but the recent successful application of sand-pumps to the improvement of the Mersey bar seemed to indicate a possible new departure in the treatment of sandy estuaries and outer bars.

Mr. C. P. FOWLER stated that the Burry inlet, fronting the Mr. C. P. seaward portion of the River Loughor in South Wales, was some- Fowler.

Mr. C. P.
Fowler.

what peculiar, containing two estuaries, the inner estuary terminating with Machynys Bluff on the north, and Salthouse point on the south, and the outer one with Whiteford point on the south, and the main land at Pembrey on the north, *Fig. 8*. The chief ports within the estuary were Burry Port and Llanelly, both on the north side, Penclawdd and Loughor on the south having now sunk into insignificance. At Llanelly, springs rose 22 feet, and neaps 17 feet; and the draught of vessels frequenting the port was from 14 to 17 feet, owing to the width of the entrance to the dock being only 31 feet, which was in many cases narrower than the beam of vessels drawing 17 feet and even less; and the port was handicapped in consequence. The Harbour Commissioners had endeavoured to train a channel from Penclawdd past Llanelly,

Fig. 8.

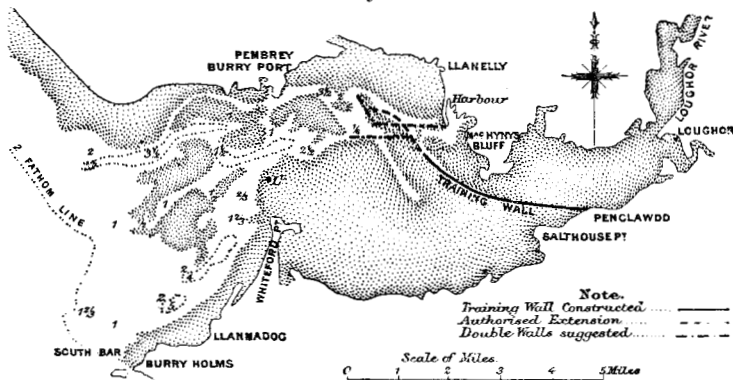


by means of a single training-wall. In its natural condition, the ebb-tide was prevented from flowing past Llanelly, in consequence of the embayed position that port held, and primarily owing to the existence of a hard low scar which projected out from Machynys Bluff. The portion of the wall already constructed was shown by a full line in *Fig. 9*, the authorized extension being shown by a dotted line; and the effect of this wall on the channel between Llanelly and Penclawdd was as follows:—The ebb of the Loughor passed along the north side of the estuary, from Loughor to a point about midway between Penclawdd and Machynys; and above this point, the wall had been useless. From Machynys, the low-water channel followed the course of the training-wall, which was about 3000 feet from the harbour light at the entrance to Llanelly harbour. There had been a general lowering of the banks between the

Mr. C. P. Fowler.

harbour and the wall, but no increase in the available depth into the harbour, the channel to which was as much subject to alteration now as before the commencement of the wall, and was only kept open by the water flowing from artificial scouring reservoirs in the harbour, and by a suction dredger. A bank, 9 feet above datum, intervened between the channel from the harbour and the channel along the training-wall; and it was questionable whether the original authorized line, shown on *Fig. 9*, would ever succeed in concentrating the two channels into one. There still existed a mile of sandy foreshore to the north of the proposed line of wall; and, therefore, with only one wall, the channel would still be able to wander about, and would probably go to the south, since there would be about 3 miles of estuary to the south on which the flood-

Fig. 9.



tide might become concentrated. The intervening sandbank referred to above terminated a little below the present termination of the wall, and would probably follow the training-wall down, and was the result of a trained channel which was too wide for the amount of water to be dealt with; and yet had the wall been any nearer the Llanelly shore, the flood-tide would probably have set to the south side of the wall. The water from the scouring reservoirs impinged against the intervening sandbanks, but was unable to maintain a channel through it, as the sluicing was only done at low water, and the scouring power was therefore intermittent; whereas the scour along the training-walls was perpetual, and the intervening banks maintained its position. The water from the reservoirs, therefore, after flowing in a southerly direction from the harbour, rebounded against this bank and flowed northward; and

Mr. C. P. the line of deepest water was consequently so circuitous that
Fowler. vessels were unable to follow it. He concluded that training a channel through an estuary by means of one wall would not produce satisfactory results. He had suggested an alternative scheme, consisting of two walls, the northern one of which would prevent the water from the reservoirs encroaching too far into the north shore; the point of confluence of the two low-water channels would be nearer the harbour; and the channel would be led into a more central course through the estuary.

A comparison of old and recent surveys of the Burry Inlet, *Figs. 8 and 9*, showed that the low-water channel had completely left Penclawdd, and from Llanelly to Burry Port was much nearer the north shore; whilst the deep pool at Burry Port had extended further east, and the available depth into the harbour was about 6 inches less. From Burry Port to sea, the south channel appeared to be filling up, judging from the diminution in the area of the 2-fathom line; but the north and central channels had remained fairly stationary. The sandbanks were much lower; and the seaward 2-fathom line had advanced about a mile in an easterly direction, towards the harbour.

The case of Llanelly afforded an instance of the inability to adopt a hard and fast rule for the treatment of an estuary; the natural configuration and the side upon which the chief industrial towns happened to be situated affected the question very materially. From experience on the Tees and Ribble he had derived the following impressions: However accurate the theory of training-walls slightly diverging towards the sea might be, there would be a tendency for the flood-tide ascending such a channel to become concentrated, and to attain an increasing velocity as it ascended, resulting consequently in a "boil" in shallow channels, and a tendency to force sand into the upper reaches; and unless the channel received tributaries on its way to sea, the velocity of the ebb current would become more sluggish through expanding in the lower reaches, and lead to deposits. He had observed the flood-tide at springs ascending the Ribble; and after the training-walls, which were about 10 feet above low-water level, had been covered, the tidal water ran up the trained channel with a perceptible elevation of 1 foot above the general level of the water at the back of the walls, and at a velocity of about 6 knots an hour. The velocity of a current was either subject to the head of the tidal wave, or the inclination of the bed of the channel; and it therefore appeared that the width of a channel should not be unduly restricted, so as to necessitate an abnormal velocity at any

particular point, necessary to fill the receiver above that point; and in order to prevent accretion, the width of channel at any particular point should have some definite proportion to the duration of the flood, either present or anticipated, consistent with a normal velocity at that point. It would be better to provide for an increase in tidal volume than risk excluding or checking the propagation of the flood-tide by endeavouring to arrive too near a theoretical capacity of channel.

Bars, bends, and sandbanks tended to keep up the level of low-water in the upper reaches; and by cutting through two bends on the Tees the low-water level at Stockton was considerably lowered. Curves therefore, which might be termed horizontal bars, should be avoided in any scheme of river improvement. The dredging away some clay bars on the Ribble, between 4 and 6 miles below the dock entrance, resulted in the lowering of the low-water level at the dock about 6 feet. By observing the level of these bars, it should be possible to ascertain the length of training-walls required to obtain a certain depth at a particular point above, as there must be an inclination per mile in the bed of a river which was normal; and after this had been attained, dredging must be resorted to. It was probably a mistake to train a channel too near one particular shore, with the expectation that the hard mainland would obviate the necessity of two training-walls. The depth of a trained channel in a sandy estuary was dependent, to a great extent, upon maintaining the top of the wall at a uniform level; whereas, by trusting to the mainland to act as a training-wall, no regularity of contour could be depended upon, and irregularity of contour led to distortion of currents and the formation of banks.

As training-walls were intended to train the last of the ebb and the first of the flood, so that the trained channel was consequently the deepest, it would appear to be incurring unnecessary expenditure to construct them to half-tide level, thereby inducing accretion, and prejudicing the stability of the wall if accretion did not take place. The training-walls on the Ribble had not proved so successful as was anticipated, probably in consequence of the channel being trained of necessity too far to the north of the estuary, as the inhabitants feared that if the river was trained more through the centre of the estuary the piers at Lytham and St. Anne's would be affected. The flood-tide and prevailing winds from the westward had, in consequence, the whole of the estuary to the south of the training-walls to work upon; and there was a tendency for the sand to be forced up in wedge fashion to the upper part of the estuary, and to drop into the channel.

Mr. C. P. Fowler. prevailing winds and gales in expansive estuaries like the Tees, the Ribble, and the Burry Inlet, were probably as important causes of alteration in the banks and channels as the currents themselves; and when possible it would be better to train channels in the direction of the prevalent winds rather than transversely to them, so that wind-driven sands might drift in the direction of the channel rather than across it.

The width between training-walls and the rate of their divergence were probably of greater import in rivers with a high range of tide and a rapid inclination of bed, than in rivers with an average range of 15 feet. The number of rivers on the west coast, the deepest inlet channels of which pointed in a direction opposed to that of the tidal wave of the ocean, seemed to favour the supposition that the inlets were more subservient to the flood than the ebb. The south breakwater on the Tees was considered to have prevented the beach drifting across the outlet; and the bar was gradually lowered by the scour concentrated thereon by the training-walls.

Mr. Bourdelles. Mr. O. BOURDELLES observed that, whilst rendering due respect to the science and learning of these distinguished engineers, he considered that there was an important omission in their Papers in respect of the study of the laws of the tidal currents in rivers or estuaries, and the influence of these currents on the designs of improvement works. This question was, however, one of the most important for such designs, since the currents shaped the channel, and their scour provided the requisite depths, or at any rate their normal maintenance. Nevertheless, engineers had hitherto almost entirely confined themselves to obtaining the velocity of the currents at the surface by some cursory observations, or to the calculation of their mean velocity by approximate methods; and relying on these data, had, without any proof, extended the laws of the flow of water in rivers to tidal currents. This wholly unscientific method was liable to lead to serious errors and most unfortunate results. As an instance, he would describe the results he had arrived at when he had to draw out a scheme for improving the estuary of Lorient.

Previously to the preparation of this scheme, innumerable observations had been made during several years of the velocities in various suitable sections of this estuary; and at stations 65 feet apart, in each of these sections, the rates of flow and the directions of the currents were noted at five different depths, namely, near the bottom and near the surface, at mid-depth, and at two intermediate depths. These observations were carried on un-

interruptedly during the whole day, at intervals of only a few minutes, so as to give the distribution of velocities in the same vertical at all times of the tide; and they were continued at the same station throughout half a lunation at least, so as to determine the influences of neaps and springs. The observations were repeated as often as necessary for the purpose of verification, and especially during the floods of the two rivers which formed the roadstead of Lorient. Brüning's tachometer was employed for measuring the velocities; it consisted of a disk of the density of water, kept perpendicularly to the current, and connected by a thread passing through the groove of a pulley to a steel-yard placed, out of the water, on a raft which carried the whole apparatus; and the graduated dial of the steel-yard indicated the pressure of the water against the disk. By this very simple contrivance the whole vertical of a station could be easily and rapidly observed, for which purpose the raft was provided with a metal cable anchored vertically on the bottom by a heavy weight. The pulley of the tachometer carried a socket, suitably weighted, attached to the cable; and a marked line enabled the apparatus to be raised or lowered to the desired position. A rudder, placed at the same height, indicated the direction of the current, by means of a wooden rod raised just out of the water, and terminated by a pointer turning on a fixed base. This expeditious process enabled the observations to be multiplied to such an extent as to indicate the phenomena most clearly; and therefore he was in a position to state the precise laws of the rate and direction of the currents, under all conditions of the tide, at the approaches of Lorient.

The flood current always commenced near the bottom, and gradually extended its influence upward to the surface, in a period which varied considerably according to circumstances. Where the channel was very narrow, a few minutes sufficed for the flood current to reach right up to the surface; whilst at other places, not less than half an hour to three quarters was required at spring-tides, and often over an hour and a half at neaps. The maximum velocity of the flood current was near the bottom at the beginning of the rise of tide, and remained in the lower part of the water up to half-tide; but from this period it rapidly approached the surface, and continued near the surface till high water. The ebb current conformed to the same laws, for it began at the bottom, and extended gradually upwards to the full height of the water. The maximum velocity, moreover, of the ebb was found at first near the bottom, remaining in the lower portion of the stream till half-tide; and then it rose rapidly

Mr. Bourdelles. towards the surface, near which it continued till low water. The period which the ebb current occupied in spreading from the bottom right up to the top varied according to circumstances, and under the same conditions as given for the flood-tide. During land floods, however, sufficiently large to make the fresh water predominate at the surface, the ebb current extended nearly simultaneously from bottom to top, just as if the channel was very narrow. Strong winds, also from the sea, and the very high tides which resulted, had a disturbing influence; but except under these unusual conditions, the above rules were always verified.

Generally there was no slack water in the mass of water, for the flood or ebb currents commenced at the bottom, when the contrary currents of the tide coming to a close, were still flowing at the surface. Accordingly, on the same vertical, a current and a counter-current co-existed, till the bottom current, spreading gradually to the top, stopped the surface current; and these counter-currents lasted, with varying velocities, for periods which might reach three-quarters of an hour at springs, and an hour and a half at neaps. The period of their co-existence varied in inverse ratio to the tidal coefficient, the section of the channel, the fresh-water discharge, and the force of the wind, or in a contrary sense to the causes which increased the rate of flow of the waters.

The distribution of the tidal currents, manifested by the experiments made at the approaches to Lorient, could not be an isolated phenomenon, but was clearly a local indication of a general law which sufficiently varied observations would doubtless eventually establish. Already a number of facts had been ascertained confirming this law, especially in relation to the beginning of the flood-tide, many very convincing examples being quoted in "The Pilot of the West Coasts of France,"¹ and in the nautical directions published by the French hydrographical department, particularly in those relating to the Congo. Accordingly, though the phenomenon had not yet been studied in detail, like at Lorient, it was nevertheless known to most sailors. Although the action of the ebb current had not been so clearly established by ordinary observations, it was not less proved by uncontested facts; and it was to its action on the bottom at the commencement of the fall of the tide, that the depths, often considerable, found in tidal rivers must be attributed, and which could not be accounted for by the

¹ "Le Pilote des Côtes Ouest de France," 1873, vol. i. p. 336, and vol. ii. pp. 197, 294, &c.

ordinary flow of water in rivers. Thus at Lorient, where the Mr. Bourdelles. surface currents did not exceed 4 knots, depths of 105 feet at low water of equinoctial springs were met with; and at the mouth of the Congo the depths exceeded 1,200 feet. The distribution of the currents of flood and ebb might, moreover, be explained in a plausible manner as being a consequence of the action of the tidal wave, on the condition of regarding it as a wave of oscillation, and not of translation as was more often wrongly done.

Though the subject admitted of further development, he thought that he had proved that a detailed investigation of the distribution of the currents at the different states of the tide should, in each special case, precede the design of schemes for the improvement of rivers and estuaries. Such an investigation would have the advantage of manifesting the use that might be made of the bottom currents at the beginning of the rise and fall of the tide. It would probably show that, owing to the action of these currents, the best way, in most cases, of improving rivers consisted in forming as deep a channel as possible by dredging, whose section below mean low water could be easily determined by practical considerations, and whose maintenance could be effected by low training-walls raised to about the level of low water of neap-tides.

Mr. A. F. FOWLER observed, with reference to Mr. Vernon-Mr. A. F. Fowler. Harcourt's remarks as to the assistance given to the designing of river works by the use of models, that, while admitting the interesting nature of such experiments, he considered that the excessive relative weight of the particles acted upon by the current available in the models, compared with the current under ordinary conditions; and the absence of wind-action in any way approximating to nature, made the results obtained from the experiments of no value for practical purposes. Mr. Vernon-Harcourt and Mr. Partiot both referred to the action of prevalent winds in affecting the outlets of rivers; but the precise action of the wind was dealt with very briefly and incompletely, and as described was not in accordance with his experience. When the direction of the prevalent wind directly faced the outlet of a river which was environed by exposed sandbanks, the sand was drifted in a direction parallel with the stream; and where the area of exposed sand bore a large proportion to the area of the channel, this parallel drifting was a matter of the greatest importance. The estuary of the Ribble extended over some 45 square miles, of which about two square miles were low-water channel, and 40 square miles were sandbanks exposed for four hours every tide.

Mr. A. F. Fowler. The estuary was entirely open to the prevailing south-westerly winds; and even during moderate gales, the clouds of drifting sand on the 10 miles of north foreshore between Warton and Southshore were so dense as to make it almost impossible to walk against the wind. Anyone who had seen the drift sand on this estuary during equinoctial gales, must be impressed with a sense of the great difficulty which would be met with in maintaining any channel across its direction. His experience had led him to the conclusion that in such cases the action of the wind upon the current was of secondary importance to its action upon exposed sandbanks.

Mr. Fleury. Mr. J. FLEURY remarked, with regard to the improvement of the outlets of tideless rivers, that the great success achieved by Sir Charles Hartley at the Danube justified Mr. Vernon-Harcourt's conclusions in giving the preference to jetties over dredging; but, in his opinion, this definite conclusion should not be regarded as a general law applicable to every case. He would remind Mr. Vernon-Harcourt of the discussion on this subject at the Navigation Congress at Paris in 1892, and the first resolution of the Fourth Section of the Congress,¹ recommending the trial of dredging in the first instance, before resorting to the execution of definite works, the results of which were never absolutely certain. Within recent years the operations of dredging had been greatly perfected, so that it was now possible to remove large quantities of alluvium from estuaries at very low prices. In several instances it might be quite as economical, and even more so, to expend upon dredging a sum equal to the interest and repayment of the capital required for the construction of jetties. Moreover, with dredging, there was the further advantage of being able to modify its action on the currents, in accordance with the new conditions which might arise, and not to pledge the future. These considerations applied equally to the estuaries of tidal rivers; and the improvement in depth obtained over the Mersey bar by dredging alone was an encouragement to those who desired that the same method should be tried at the Seine outlet, between Berville and the Amfard deep.

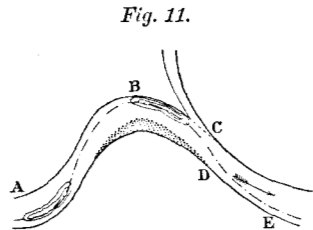
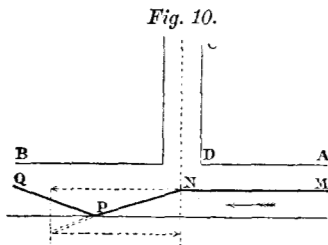
With reference specially to the improvement of the Seine estuary, which was still the subject of numerous discussions in his country, and upon which a definite solution was far from having been reached, Mr. Vernon-Harcourt's Paper contained some very significant information. All the schemes of jetties and training-

¹ V^{me} Congrès International de Navigation Intérieure, Paris, 1892, Procès-Verbaux des Séances des Sections, pp. 650-656.

walls described by Mr. Vernon-Harcourt had strenuous supporters Mr. Fleury. amongst French engineers; and the only point on which they agreed was, that under no consideration should the tidal water entering the estuary be reduced in volume. The results obtained by Mr. Vernon-Harcourt, in his ingenious small-scale models, furnished a convincing proof of this. Mr. Partiot, in his present Paper, acknowledged this, and yet he again brought forward his oft-proposed scheme of a transverse breakwater, Fig. 4, Plate 4, whose only effect would be to cause accretions which would greatly reduce the capacity of the estuary, and in a short time compromise the existence of any channel. Mr. Partiot's ideas were far from receiving the support of most French engineers. He (Mr. Fleury), whenever opportunity offered, insisted upon these two considerations: (1) That there was in every scheme for training an estuary, a coefficient of probability, which often reached the limit of an absolute uncertainty as to the results; and (2) that dredging operations, actively carried out as on the Mersey bar, would produce an immediate effect which could be easily maintained, and that, as the cost of dredging was being constantly reduced, there was every advantage in trying this method before any other.

Mr. R. LE BRUN considered that the investigations for the Mr. Le Brun. improvement of rivers and estuaries would be remarkably facilitated if the influences the great maritime phenomena exercised upon each other were better understood, such as the transport of sediment by the water, and the action of winds, currents, and waves upon the coasts and the bottom. Numerous works had already afforded appreciable results, practical rules had been laid down, and laws indicated. Experiments also tried with small-scale models had yielded some valuable information; but they were only at the beginning of their investigations, and he desired specially to draw the attention of engineers to the reciprocal action of currents on each other. The action of a continuous current on a river with a shifting bed, and the influence of the curvature of the banks on the position and depth of the channel, had been investigated; but to complete the inquiry into the laws of rivers, it was expedient to examine the effect of a large tributary, which might produce extensive perturbations in the main river both above and below its confluence. Thus, assuming that a tributary CD, Fig. 10, joined the main river AB nearly at right angles, this secondary current would check the main current; and the loss of velocity would result in a rise of the water-level above the confluent, leading to floods and the formation of shoals. The molecules passing in the direction MN would be diverted at N in

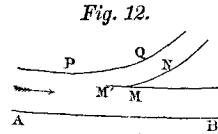
Mr. Le Brun. the direction of the resultant of the two velocities towards the left bank at P; and if the bank was firm, they would be reflected towards Q, or the bank would be eroded if soft. Large works had been carried out to regulate the confluence of some large rivers badly directed by Nature, so as to mitigate the disasters which periodically resulted. If the lines of the banks and the junction of the streams were under control, it would be advisable to arrange them so that the current of the tributary might assist in directing the main current suitably and deepen the channel. In a winding



river, A B C D, *Fig. 11*, suitably regulated, the deep places would be found in the concave bends, a little down-stream of the summit of the bends; and the channel hugging the concave banks passed across from one bank to the other at the change of curvature. It followed that the best position for the mouth of the tributary would be at the point of inflexion C, just below the concave bank, so that the secondary current would tend to direct the main current towards the next bend, the deep hollow above would prevent the formation of the shoal which was generally produced above the confluence, and would scour the shoal which tended to form at the point of inflexion between C and D. In some special cases, when the tributary was not navigable and its level could be raised without inconvenience, it might be made to fall over in a thin sheet on the concave bank, so that its waters would join the main current without any appreciable transverse motion, thus augmenting the volume of the stream without modifying its direction. The fall of the waters of the tributary on the convex bank, where accretion took place, would put the sediment into suspension and occasion its transport into the deep hollows, and would disturb the state of the river; but this action would be useful if it was desired to remove the deposits at this bank.

Considering next the inverse case of a river branching off into two channels at a point M, *Fig. 12*, the proportion of the flow through each channel could only be determined by the section of

the channel, and the fall, direction, and nature of the current, Mr. Le Brun, according as it was due to ordinary flow or to tidal propagation. The distribution of the flow, however, could be greatly modified by a spur M'M from the point, whose length and direction exercised a most important influence on the discharges; and by this means it had been possible, at the bend of the Rhone delta and at the Bec d'Ambès on the Gironde, to give each channel its suitable discharge.



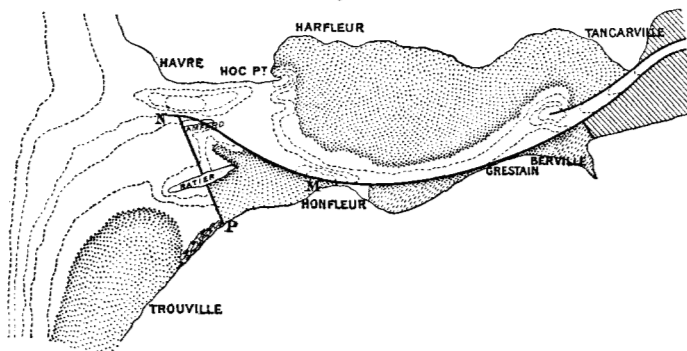
The direction should be adjusted so that the flow should be free from eddies, which would impede the discharge, diminish the velocity of the current, and produce silting up above the point of separation in the channels themselves. Great care should be taken to give such a direction to the bank A B that the current might not be driven into the less important branch; and the spur should be placed so as partially to shut off the branch P Q, and to facilitate the admission of the current into the main channel; and dykes should be constructed if the banks were not firm enough or high enough to prevent the two currents from falling into each other, and along a sufficient distance to secure the direction of the current. These works should be so designed in tidal rivers as not to impede the ebb currents, and to give them as much as possible the same direction as the flood-tide, of which the works at the Bec d'Ambès furnished a most interesting example. The study of these phenomena had a much greater and more general importance than those simple ones previously examined; they were found above and below the numerous islands scattered over some rivers; and their effects were seen in the bed of rivers in which the width was very large in proportion to the depth, and the form of whose banks had little influence to maintain the direction of the currents flowing in various directions under the very different actions of the flood and ebb in the tidal portion. They were specially found in estuaries at the meeting of the flood and ebb currents, running in various directions in the secondary channels, and in the blind channels between the banks. These phenomena were more obscure and more thoroughly altered when the currents flowed through masses of waters of variable depth, and of varying density according to the saltness and the materials in suspension; but a precise knowledge of the effects of the meeting of two definite currents should throw a great light on the probable results of these more complex conjunctions. Examples should be sought in estuaries well sheltered from the wind by high hills, and separated from the sea by a narrow neck which fixed the direction of the flood and ebb

Mr. Le Brun. and preserved the estuary inside from disturbance by storms. Under such conditions, the movements of the mass of water would preserve a certain permanence which would enable the effects of the currents to be better distinguished.

The Foyle estuary, which was enclosed by Macgilligan Point, Fig. 15, Plate 4, and into which the river flowed at the head of the estuary through a narrow channel at Culmore Point, above which the flood-tide accumulated large volumes of water, combined the best natural conditions for this investigation; whilst its bed, composed of sand and silt, was essentially movable. The principal channel exhibited a remarkable average regularity, following the great concave bend of the northern shore, under shelter of the Donegal mountains; and the sandbanks rose from the channel with a very gentle slope to the south shore. These banks were intersected by blind channels, serving for the admission of the flood-tide and also for the outflow of the waters covering the bay at the commencement of the ebb. All these blind channels opened into the main channel, and having a sharp slope seawards gave rise to transverse currents in the principal channel. Above the confluence of each of these blind channels, shoals had formed in the main channel; and below their confluence there were deep hollows. The main depth of the principal channel increased from the head of the estuary down to the neck, where it attained a maximum; and a bar had formed beyond the neck, as well as Tans bank outside the channel, and separated from the coast by a well-defined hollow. The moderate changes in depth, noticeable in the main channel, seemed due to irregularities in the shore, such as Quigley Point, and the secondary current to the west of the Great Bank had driven the channel against the shore a little above Moville. If these results were compared with those observed at the meeting of two ordinary currents, the same effects would be noticed, namely, the secondary current pushing the main current against the opposite bank, and the formation of a hollow below, and a shoal above the confluence. In the estuary of the Foyle the ebb current appeared to preponderate, as in the bay of the Seine. There was here too close a concordance for it not to be attributed to cause and effect; and he believed that he had been able to notice similar phenomena, even in the Seine estuary, though the great and frequent changes there prevented equally characteristic effects being noted.

He had endeavoured to apply these ideas to the improvement of the Seine in 1888, when he studied the question in conjunction with Mr. de Coene. Mr. Vernon-Harcourt had submitted their

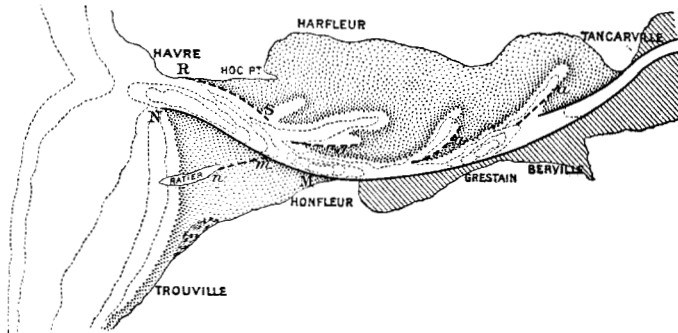
scheme to the test of his remarkable series of experiments; and Mr. Le Brun, without reopening the discussion as to which of the proposed schemes it would be advisable to adopt, he (Mr. Le Brun) considered that it would be advantageous to derive information from the results obtained, and that it would also be desirable to confirm them by supplementary experiments, which could be carried out in the large model of the Seine established at Rouen by the engineers of the Seine. The results obtained by Mr. Vernon-Harcourt showed that with the aforesaid scheme in the Seine model, *Fig. 13*, the flood-tide flowed at first towards Hoc Point, that a deep though small roadstead was scoured out in front of Honfleur, that the channel followed the training-wall up to Grestain, a little below Berville, where it diverged, probably owing to the flood-tide running towards the bottom of the bay, and

Fig. 13.

then came back between the training-walls near Berville, and that the channel though fairly regular had a small width. The anticipations, therefore, of the framers of the scheme were in a great measure realised; whilst it should be noted that the absence of the proposed concave training-wall, R S, had allowed the flood-tide to extend its action towards the north-east, whereas the probable effect of this training-wall would have been to turn the great depths towards the south-east, and to join the hollow of Honfleur, as shown in *Fig. 14*. The dredging of the portion of the Amfard bank within the trained channel, as intended, would have still further increased this effect. The bend in the channel at Grestain showed the necessity of modifying the action of the flood-tide, and it would have been interesting to try in the model the influence of submerged dipping dykes, *a a''* as shown in *Fig. 14*, which would

Mr. Le Brun. probably have pressed the channel against the training-wall.¹ Mr. Vernon-Harcourt, in his own scheme, appeared to have doubled the width between the training-walls above Berville, and he had certainly obtained remarkable results; and it would have been interesting to have tried this modification with their project, which probably would have both widened and deepened the channel. The low training-wall MN in their scheme, *Figs. 13 and 14*, was necessary, and appeared adequate to secure the direction of the channel between Honfleur and Havre, whereas the breakwater, NP, *Fig. 13*, seemed to promote too great an amount of accretion in front of Trouville. By raising the concave training-wall MN above high-water, and dispensing with the breakwater NP, the sands outside would settle behind the Ratier bank; and this deposition might be hastened by a low dyke *mn* between the Ratier bed and the training-wall. A certain amount of water

Fig. 14.



surface in the estuary would undoubtedly be lost, but, on the other hand, the protection of the channel would be more effectually secured; and direct experiment would show whether these anticipations were justified. It appeared that the training-works in the upper part of the roadstead, added by Mr. Partiot to the scheme under consideration, were unnecessary, and in any case should be deferred until it was considered advisable to let only the clear water coming from Cape Antifer and La Hève enter the estuary. The experiments with models, which he desired to see completed, would enable the correctness of his hypothesis to be determined, or in any case to obtain a solution of the problem he had put forward, and the importance of which was evident. It

¹ *Mémoires de la Société des Ingénieurs Civils*, 1888, vol. i. pp. 294 and 313.

was to a great extent within the power of the engineer to modify, Mr. Le Brun. to diminish, or even to suppress transverse currents; and, on the other hand, he could create them, concentrate them on a given point, or distribute them over a long overfall. There was, accordingly, a considerable force in the tide, which should be always taken into account, and which could often be utilized with advantage, and which, consequently, it was most important to understand fully. He would, however, go still further, for the experiments already carried out demonstrated the possibility of reproducing natural phenomena in all their complexity with small-scale models, which opened out a vast programme. Could not these investigations be carried out in a rational manner by commencing with simple phenomena and proceeding to their combination? Taking only a single example, the silting-up in a bay might be investigated according as it was more or less open, and according as a stream flowed into it or not, of which the discharge varied; and the influences of winds, currents, and tidal range might be noted. These investigations, judiciously chosen, would rapidly augment the range of existing knowledge, and the number of undoubted rules which collective experience had already enabled congresses to draw up; they would enable maritime schemes to be entered upon with greater promise, and they would effect the solution of problems hitherto considered insoluble. Where still powerless, they should be supplemented by observation, for comparison, analogy, and experiment were the means of progress of the physical sciences.

Mr. W. DYCE CAY had previously given his observations and Mr. Cay. conclusions as to the formation of, and remedy for bars at the mouths of tidal rivers.¹ He felt some interest in the schemes for the improvement of the mouth of the Seine, as Mr. Partiot had sent him some of his writings last year; and the plan he should consider best differed in some important respects from that shown by Mr. Partiot in Fig. 4, Plate 4. He would construct a north breakwater extending from Cape La Hève, at a point about 4,100 yards north-east from the Havre entrance, in a south-south-west direction, the same as the line of the Hève lighthouses, for 6,000 yards. Also a south breakwater, extending from Villerville on the south coast for 8,600 yards, in a north-west direction; these two breakwaters to form enclosing arms for the mouth of the estuary, with an entrance 1,300 yards wide. Inside of them, he would train the channel in a tolerably straight course, mainly by

¹ Minutes of Proceedings Inst. C.E., vol. c. p. 180.

Mr. Cay. dredging, to join the present trained channel at Berville. The cost of the two breakwaters would be about £3,000,000.

Prof. Gaudard. Professor J. GAUDARD remarked that, in hydraulic works especially, facts often set at naught theories; and, therefore, statistics, and the results of observations, such as abounded in Mr. Vernon-Harcourt's and Mr. Partiot's Papers, were valuable acquisitions which theory must cordially welcome. It was only upon points where doubts and differences of opinion were manifested, that persons, without personal observations to bring forward, could venture to express their views, such as the divergence which existed between the two Authors as to the best method of permanently deepening the outlet-channel of the Seine. Mr. Vernon-Harcourt advocated the prolongation of the training-walls out to the sea in a trumpet shape; and his ingenious experiments with little models, imitating the tidal ebb and flow, had confirmed him in this opinion. Unquestionably, such an entrance was the best for facilitating the introduction of the flood-tide, and for conveying the tide with as much regularity, and with as little impediment and loss of force as possible, and with an increase in height far up the river, and thus enabling it to overcome the friction in the channel and the opposing current of the fresh water. The beneficial results already realised at the Port of Rouen by the training-walls hitherto carried out, ought to be further augmented by the regulation of the outlet-channel. The rising tide would be better directed than at present, where a portion of the flood-tide, diverging right and left, formed hollows or pockets which, being gradually elongated, enticed the ebb current to desert its old channel, resulting in the shiftings of the main channel so unfavourable for navigation; though, on the other hand, these wanderings had the advantage of lowering the whole surface of the estuary by degrees, and of preventing the consolidation of the sandbanks, thereby leaving them exposed to the action of the sea, and thus aided in the preservation of the tidal capacity of the vast estuary, as had been pointed out in the case of the Mersey estuary. The completion of the training-works would no doubt lead to fresh accretions at the sides, occasioning a certain loss of flow at a high level; but this would be advantageously compensated for by the increase of the tidal volume ascending the river; and the later return of this water on the ebb than if it had remained in the bay, would render its scouring action all the more efficient, as the tide would have had time to fall lower. Moreover, since at a certain distance up the Seine the low-water line was higher at springs than at neaps, owing to the larger mass of tidal water not having

time to flow away, it appeared that at spring-tides, when the clearing out of the estuary was mainly effected, there was an excess of tidal water, and that some silting up was accordingly admissible. Besides, a widening-out of the training-walls, so as to come close to Havre on the one side and to Honfleur on the other, would not greatly curtail the existing tidal capacity; and there would be compensation for any loss of capacity, in the deepening of the channel and in the freer ingress of the flood-tide. Prof. Gaudard.

An objection might be raised that storms also would disturb the bay more, and that the tide also might possibly increase somewhat in violence. To this it might be replied, that the Seine estuary was a veritable gulf or an arm of the sea, with no pretention to become wholly a refuge harbour—a duty which devolved upon Havre with its proposed extensions; that favourable periods could be selected for future dredging operations in the estuary; and that, lastly, the bore was only dangerous at known times, of which vessels navigating the Seine were duly warned; and as it was only a result of the tide, it would be inconsistent to try to exclude it whilst favouring the admission of the tide, unless some movable weir was invented strong enough to resist it.

The only further criticism remaining to be made of Mr. Vernon-Harcourt's scheme related to the great width left at the outlet, in regard to the conveyance of the sands to the sea; for the ebb current, spreading out like a large fan, would lose its scouring efficiency, and would leave too much of the necessary deepening to be effected by dredging. It was here that Mr. Partiot intervened with his narrowed outlet; and immediately that the ebb was given only one point of issue, the waters would be forced to converge to this outlet from a distance, and to maintain a fixed, deep channel in that direction. Similarly the flood-tide, in seeking the neck, would scour the bar over which it would otherwise only glide. This view seemed the more plausible as Mr. Partiot supported it by observations on a certain number of rivers; but, on the other hand, he took little account of Rouen, probably considering that the claims of that port had been already amply satisfied, and that it had nothing to fear from new works. Mr. Partiot suggested that a great width of channel was less needed for the propagation of the tidal wave than an adequate section, and that it would be quite as good to give the flood-tide a narrow and deep opening as a great width of shallow entrance with its retarding frictional resistance. This remained to be seen; and, moreover, would the compensation of sectional area be sufficient? Next, in the case of a seething and eddying mass of water resulting from the

Prof. Gaudard. dynamical inrush, it would be hazardous to rely on formulas of flow through narrow orifices. Mr. de Coene, an advocate of Mr. Partiot's scheme, said that it would be a mistake to compare the propagation of the flood-tide in the Thames and in the Seine, because in the Thames, the tidal currents entered precisely in the direction of the mouth; whereas in the Seine, the filling of the estuary was effected by derived currents, more or less interfered with. Nevertheless, however carefully the course of the currents was studied, and the entrance placed in the most favourable direction, it was difficult to admit that a long breakwater placed across the estuary, whilst affording shelter from storms, would not also to a great extent arrest the acquired impulse of the masses of water coming from the ocean and discharging themselves into the estuary, and that there would be no loss in the backing up of the fresh water, and no diminution in the distance to which the flood-tide extended up the river. It would, indeed, be a sheltered roadstead, and too well sheltered. On approaching the coast, the flood-tide was far from being a geometric wave, where the molecules revolved in closed orbits without advancing; it was really an inrush, and wherever a creek existed to be filled the current had to travel there. The leading idea, however, of Mr. Partiot was to convert the estuary into a large natural sluicing-basin, superior to an artificial sluicing-basin in possessing an enormous volume of water, and inferior to it in not having the power to introduce the mass of water, and let it loose, at the most suitable periods. At Honfleur, a sluicing-basin, 143 acres in extent, had been reclaimed from the estuary, the filling and emptying of which was regulated by movable openings at different places. Its filling was effected over a weir, admitting only the top cleaner layers of a high tide, so as to prevent the ingress of sand, involving a certain checking of the flow which was quite allowable when it was not a case of receiving a tidal impulse to be transmitted at once to a distance. Moreover, the emission of the water for scouring the entrance-channel to the port, by opening the revolving gates, was only effected when a good fall was obtainable, by the lowering of the tide, for creating a powerful current which acted upon the bed of the channel when least protected by a superincumbent layer of water. Being unable to erect an immense movable weir in the sea, to regulate in a similar manner the enormous scour of the Seine estuary, Mr. Partiot had aimed at doing what he could with fixed works. His breakwater would, indeed, keep out a portion of the sands during the flood-tide; and during both the flood and ebb, the narrow opening would concentrate into itself the scouring

currents ; but as this opening could not be temporarily closed so as Prof. Gaudard. only to let out the water after the fall of the tide outside, the ebb would to a great extent be dissipated by slow and feeble outflows, as at first the current would be weak and the sandy bottom too much covered with water. Accordingly, most of the tidal water entering the estuary would be of little service in its outflow, beyond delaying the descent of the upper waters till these had acquired some energy ; but since, under the existing conditions, the tidal water had not time enough at springs to flow fully out, this would be still more the case with the narrow outlet. There would, therefore, be a violent scouring current near low water ; but the effect of the narrow outlet would be in excess, since a portion of the tidal water enclosed would remain inside unused, to be driven back by the ensuing flood-tide. Instead, therefore, of erecting a breakwater, it might be preferable to form a low cross-dyke, only slightly raised above low water ; for if this sufficed to concentrate in the neck the scouring action of the strongest current for deepening the channel, the upward impulse of the flood-tide would be no longer materially impeded, because the flood-tide did not attain a high velocity till past half-tide, and as soon as the low dyke was overtopped it would flow freely over. From this it seemed that the schemes of Mr. Vernon-Harcourt and Mr. Partiot were not irreconcilable, but that, on the contrary, they would supplement each other, in a happy manner, carrying them out, moreover, cautiously in low lines, capable of being subsequently raised to some extent as experience might dictate. Thus the river training-walls would be prolonged in a funnel shape, greatly expanded so as to come to each side of the mouth ; and then all the middle part of the opening would be barred by a long low dyke facing the sea, and leaving preferably two passes instead of one, near the shore on each side, closing the central channel between Amfard and Ratier, and trying to deepen the other two, and to convert the bed of the estuary into two arms of a delta, ensuring deep-water access both to Havre and Honfleur. The low dyke would partially arrest the sands brought in by the flood-tide and the waves, which would form a triangular bank on the sea side ; and it would also retain a portion of the sand in the estuary brought down by the ebb, which would likewise form a triangular deposit on the upper side of the dyke, the whole forming a central island, bare at low tide, with the dyke in the middle. It was probable that the side channels, after having been primarily deepened and regulated by dredging, would maintain themselves ; because, though the tidal currents only attained their full force

Prof. Gaudard. during the latter half of the flood and the ebb, the low dyke and sandbank would scarcely interfere with the flood, beyond preventing its bringing up so much sand, and would intensify the scouring effects of the ebb on the deep channels. The progress of such great works was necessarily slow enough to enable them to be carried out in some measure as trial stages, which, by watching the first results, could be continued or modified, or even stopped, if at any point the anticipations were falsified. It was, moreover, desirable to extend the experimental methods referred to by the Authors. The small-scale models of Mr. Vernon-Harcourt were a resource where trials on the spot were not available; but the latter were clearly to be preferred when practicable, such as the wattlings of the Garonne mentioned by Mr. Partiot. For providing more solid trial structures in exposed situations, and which might, nevertheless, be removed and used again if unsuccessful, hollow concrete blocks in the form of a trough, like those employed by Mr Möller for the breakwater at the free port of Copenhagen,¹ might be used, which could be raised again by the floating crane which deposited them.

It had been pointed out by Mr. Vernon-Harcourt that the 5- and 10-metre lines of soundings at the mouth of the Seine had receded seawards 3 miles and more within sixteen years—a condition which it was urgent to remedy. The Loire estuary had given rise to similar apprehensions, more particularly as both sand from the sea and alluvium from the river came into it. Whereas Mr. Partiot, in 1871, had noted a certain stability in the depth of the channels under the action of the tides,² Mr. Carlier stated in 1878 that the deep places were filling up unceasingly, that the accretions exceeded all expectation, that an extension of the training-walls seawards could only hasten the growth of the banks in front of St. Nazaire, and that the only remedy was a length of ship-canal.³ Now, as pointed out by Mr. Vernon-Harcourt, when by the construction of this canal they had avoided pushing the sands further down the estuary, deposits tended to form between La Martinière and Painboëuf, which would involve a considerable amount of dredging to keep them down, unless means were found of stopping or reducing these deposits. The important point was to reduce as much as possible the drift of material in the rivers all along the coasts, by means of groynes

¹ London Maritime Congress, 1893, Minutes of Proceedings, Section I, pp. 38, 39.

² *Annales des Ponts et Chaussées*, 1871, (i) p. 233.

³ *Ibid.*, 1878, (ii) pp. 595 to 612.

along the sea-coast, spurs, dykes, protection of the banks of rivers flowing through plains, and, lastly, dams in steps across torrents and the reforestation of mountain slopes—works directed, in the first instance, to the protection of land from erosion, but the benefits of which extended to great distances by reducing the deposits which were injurious to navigation and promoted floods. The Loire was charged with materials coming direct from the denudation of the mountain slopes of Auvergne and Forez, or which had been eroded from its banks formed of the alluvium which had been brought down long ago. Mr. Partiot had pointed out, in 1871, that the works for securing the banks of the Allier, whilst protecting existing lands and reclaiming fresh lands for agriculture, would greatly reduce the sediment of this river and of the Loire.

Much had been already done to regulate mountain torrents, especially in France and Switzerland, with great advantage to the plains. Mr. Vernon-Harcourt had furnished an interesting example of the consolidation of a large river in his description of the improvement of the Lower Rhone. The immediate object was to facilitate navigation by scouring the bed; but directly the cross-dykes from the sides formed enclosures where the materials scoured from the central channel lodged, the banks of the river were thoroughly secured in the places where formerly they were subject to erosion. Taking account also of the silting-up in the Durance and the Isère, as well as the dams and the replanting on the mountains effected in the Lower Alps, it seemed fair to infer that the Rhone at present carried less materials to the sea than it did at the period of the abortive attempt to lower its bar. Accordingly, if the works had been postponed, they would have possessed a better chance of success, in addition to what they would have gained by adopting the Roustan branch, and leaving the flow of the other channels of the delta unimpeded.

On some sea-coasts it might be possible, by the energetic and persevering efforts of all the riparian owners, to carry out works which, though small in themselves, might simultaneously effect protection of the coast, acquisition of land, and an improved access to ports at some distance off. Thus Mr. Partiot, in Fig. 7, Plate 4, had made the interesting suggestion that groynes, besides protecting land subject to encroachments by the sea, might serve, on coasts where the drift of sand was great, to gain tracts from the sea; that these reclaimed tracts, by their projection merely, would absorb this drift and dissipate its source; and that these ports would be delivered from this disabling encumbrance, which necessitated the constant opening out a deep passage for vessels

Prof. Gaudard. across inexhaustible accretions. Dredgers would undoubtedly be always available; but, wherever practicable, the forces of nature should be turned against themselves before resorting to the costly and artificial method of dredging. In default of the power to arrest the littoral drift, attempts had been made to combine its free travel with the maintenance of the outlets of ports; but open jetties, the concave jetties of Mr. Bouquet de la Grye, and artificial sluicing proved too often only inadequate palliatives; and at Dunkirk, Ostend, and elsewhere, it had been necessary in the end to have recourse to great dredging operations. It, therefore, was a question whether there were not some places on sandy coasts where the principle of the late Sir John Coode's scheme for Port Elizabeth might be applied—of forming an island port by encircling breakwaters, sufficiently far out at sea to preserve its depth, and allowing the travel of sand to proceed unimpeded along the coast, to which the port would be joined by a bridge. This bridge, provided with lines of way, and, if desired, by endless transporting bands, would be raised above the reach of the waves, from which the port would also be protected by high parapets round the outer side of the breakwaters enclosing it. Ports had been formed quite as well, under favourable conditions, by extending quays into the sea as by excavating basins inland, the chief difficulty in the first case being to shelter the port from wave motion, and in the second case to secure the entrance-channel from accretion. Where it might be necessary for a proposed island port to have a large extent, and to comprise large quays as well alongside, the embankments for these quays might perhaps be formed by a temporary diversion of the sandy drift, by means of a dyke which could subsequently be removed to restore the primitive travel of the sand along the coast. Mr. Eyriaud des Vergnes, referring, in his Paper on "Ports on Sandy Coasts,"¹ to the proposal of forming an island port connected with the shore by an open viaduct, objected to it on the score of its great cost; but the question should primarily depend on the special configuration of the localities, which varied considerably.

The rule applied to the jetty system for lowering the bar at the mouths of tideless rivers, was the selection of one of the delta channels having a moderate discharge, and, consequently, bringing down only a moderate amount of sediment. In order, however, to carry out this principle to its full extent, a branch should be selected which could be closed at its head by a lock, and thus

¹ *Annales des Ponts et Chaussées*, 1889, (i) p. 185.

divert its discharge into the other branches, so that only the water from lockings would pass down, which would not involve much dredging for the maintenance of the depth over the bar, even in the absence of any littoral current. In this case it would be essential that the subsequent advance of the delta, through the mouths left open for the discharge, should be kept at a distance by groynes or otherwise, so as not to come back into the pass reserved for vessels. An important condition, moreover, would be that the head of the selected branch should be suitable for the construction of a basin in which the lock could be recessed, so that its entrance might not be liable to be impeded by the silt of the river. This really was the solution finally adopted at the mouth of the Rhone, except that, instead of excavating a canal, one of the existing channels would be utilized.

Mr. MENGIN-LECREULX did not agree with the principle, stated by Mr. Vernon-Harcourt, that the formation of sinuous channels was inexpedient in tidal rivers of great width, and considered that it, at any rate, required explanation. The purely undulatory phenomenon which occurred on the first arrival of the flood-tide was, indeed, governed by special laws; but directly the tidal flow had become fully established, its action did not differ sensibly from that of the ebb current. The dual action noted of the two currents was manifested when the form of the channel was defective, and especially when the lines of the curves and the distances between the summits of the successive bends were not in harmony with the width. When this width was very large, it might be difficult in practice to establish this concordance; and, in his opinion, it was only in this sense that the above principle should be accepted. The case might more particularly arise at the mouth of the river, where the widths were greater, and where the problem became complicated by the close proximity of the sea and all the resulting perturbations. Higher up a river, and even for widths of 550 to 1,100 yards, he considered that a sinuous course was as applicable to tidal rivers as to others.

The rate of enlargement of some tidal rivers, with good outlet-channels, had been found by Mr. Vernon-Harcourt to range between 1 in 90 and 1 in 30; but these ratios of enlargement, especially if relating to English miles, appeared small. He himself had arrived, after a special study of this question, at ratios of between 1 in 50 and 1 in 20 per kilometer, according to the rise of tide, for rivers under ordinary conditions,¹ equivalent

¹ "Mémoire sur la Puissance Hydraulique des Fleuves à marée," P. Mongin. Congrès International des Travaux Maritimes, Paris, 1889, p. 23.

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Lecreulx.

to between 1 in 31 and 1 in $12\frac{1}{2}$ per mile. The problem could be solved in each case by long, but simple calculations of volume, as effected by Mr. Franzius for the Weser, where he adopted a ratio of about 1 in 25 per mile for a tide rising $11\frac{1}{2}$ feet. For a preliminary approximate calculation, the formula $\frac{\Delta w}{w} = 0.065$

$(1 + m) \frac{t}{d}$ might be advantageously used, in which w was the width of the low-water channel, Δw the increase in width per mile, d the mean depth at half-tide, t the rise of tide, and $1 + m$ the proportion between the widths of the major and minor channels. This formula agreed fairly with practical experience, and when applied to the Lower Weser, where t was $11\frac{1}{2}$ feet, $d = 23$ feet, and $1 + m = 1.33$, gave 0.043 as the rate of enlargement per mile.

If Mr. Partiot's Paper was merely intended to draw the attention of engineers to narrow outlets and their effects, and to the advantage of examining in each case whether it was possible and desirable to adopt this system, Mr. Mengin-Lecreulx had no objections to raise. The theory, however, had originated in a scheme proposed by Mr. Partiot for the Seine; and if, owing to the great authority attaching to the Proceedings of this Institution, this Paper should directly or indirectly furnish an argument in favour of this project, he could not possibly give it his approval. In the first place, as Mr. Vernon-Harcourt had remarked, in the case of great rivers and estuaries, the function of an artificial narrow neck involved gigantic works, with corresponding expenditure; whilst the consequences of an error in the anticipated results, which was always possible, became all the more formidable. The closing of the Seine estuary across a width of $6\frac{1}{4}$ miles, at the bottom of a bay where very powerful tidal currents converged, would involve an absolutely unprecedented work, the execution of which, if not impossible, would at least be attended by formidable difficulties, and expenses which would be hard to estimate.

As regarded its results, this scheme gave rise to grave questions. Would not the narrow neck, placed at the side, occasion a lowering of the high-water level in the estuary, and what would be the amount of this lowering; and what would take place during construction? Was not the formation of an inner bar to be apprehended; and by what works would the continuity of the channel in the estuary be ensured? What, moreover, would be the position and depth over the outer bar, which would unquestionably be formed in front of the neck? These were all serious questions which had been for a long time discussed, and in face of which

the great majority of French engineers, the populations interested, Mr. Mengin- and the public authorities, had decided against this scheme. Lecrenlx.

Some deliberately condemned it as disastrous; whilst others confined themselves to the views that the risks and cost of construction would be excessive, that the chances of failure were too great, and that the results were uncertain and disproportionate to the works; but both sides arrived at the same conclusion. The examples from nature which furnished the basis of the argument in favour of the scheme were not complete; for the Loire, which had a neck, possessed only a very moderate navigable depth, whilst the navigation of the inner estuary of the Gironde was beginning to present difficulties. Beyond Liverpool, in front of which the Mersey flowed through a regular neck, a bar existed, sufficiently inconvenient for navigation to render it expedient to expend large sums at the present time in dredging for lowering it. The existence of a neck was not everything; and other conditions were needed as well. The port of Havre adjoined depths on the west and north-west, which were and would remain secure, and into which it would be very easy to open a deep outlet by a slight modification of its entrance, and by dredging in fine ground, which would provide a permanent improvement, constituting only a small portion of the works which Mr. Partiot's scheme would entail in order to provide a neck with the section absolutely necessary for the flow into the river. In Mr. Partiot's scheme, Havre was offered to have the waters of the Seine led to it, together with the materials they carried along, coupled with the promise that the current would drive the bar which would be formed sufficiently far out and into deep enough water. The maritime proposal, on the other hand, would afford economy, simplicity, and certainty; there was no doubt as to the choice, and it rendered the objection to Mr. Partiot's scheme absolute. As regarded the Seine, its improvement would be continued by rational means, less radical indeed, but also less dangerous, capable of being carried out in stages, and thus giving opportunities of profiting from time to time by the teachings of experience, which seemed to him in accordance with common sense. In conclusion, the plan of a neck was an interesting method to bear in mind, and to investigate, which had been usefully adopted in certain cases, though on a restricted scale, and which no doubt might again be resorted to; but it was not the sole method, nor of universal application, nor was it free from uncertainties. In large rivers and estuaries, the magnitude of the necessary works, the large scale even of the changes introduced in

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the natural conditions, and the greatness of the risks attending any mistake with reference to the anticipated results, which were peculiarly difficult to predict, constituted very grave objections to Mr. Partiot's scheme, which would often lead to a search for other methods.

Mr. De Coene.

Mr. J. DE COENE noticed that, in the Papers under discussion, absolutely dissimilar subjects had been touched upon, for rivers flowing into tideless seas, like the Mediterranean, had been considered at the same time as rivers flowing into tidal seas; whereas the action of the currents in the two cases were entirely different, and he proposed to confine his observations to the latter class of rivers, such as flowed into the sea along the French coasts bordering the Atlantic and the English Channel. He would observe at the outset that Mr. Vernon-Harcourt and Mr. Partiot had not mentioned in their Papers the experiments made upon the Seine, in imitation of those carried out by Professor Osborne Reynolds, who, by experiments, subsequent to those on the upper Mersey estuary, demonstrated the perfect concordance of results obtained with models of different scales—an evident proof of the indications that might be obtained by means of a model as to the direction in which training-walls should be carried out in the estuaries of tidal rivers. Professor Reynolds, in the later experiments carried out at Manchester, had reproduced in a V-shaped outlet changes of channel such as took place in the Seine estuary, and which constantly occurred on the Tees previously to the works carried out by the late Mr. John Fowler, and to which the Seine was still exposed, since recently the channel had suddenly shifted some miles in a few tides, passing from the north to the south of the bay of the Seine. Thus the channel which, on the 2nd of February, 1893, passed between the banks of Ratier and Amfard, changed abruptly in less than a week, in March, to the north, running close to Hoc Point, and having its outlet close to Havre. Then suddenly, on the 1st of May, it shifted to the south coast between Ratier and Villerville, where it was at the present time. These displacements traversed a width of estuary of about 4 miles. At certain places the channel changed nearly every day, and necessitated constant alterations of the buoys. It was these changes of direction of the channel which prevented its deepening, and confirmed the accuracy of the results observed in the experiments on the models of the Seine. As stated in his report on the Proceedings of the London Maritime Congress,¹ the experiments

¹ "Rapport sur les Travaux du Congrès International des Travaux Maritimes. Session de Londres, 1893," J. de Coene, pp. 21, 22.

made at Rouen with a large-scale model indicated clearly the Mr. De Coene. advisability of constructing a breakwater enclosing the Seine estuary, and leaving only an opening in front of Hoc Point, so as to scour the silt from the estuary, taking care to begin with a low training-wall along the south side, and to defer the construction of the training-wall beyond Honfleur on the north side, as Mr. E. de Churruca of Bilbao had advised them to do.¹ The same thing resulted from the opinion expressed twice by Mr. Vernon-Harcourt, first in his Paper on his little model of the Seine, and again in his Paper on his Mersey Model.² In the portion of this latter Paper headed "Introduction of Training-Walls in the Lower Estuary," Mr. Vernon-Harcourt referred to the results that might be obtained on a sandy bar by dredging, as gathered from the improvements in depth effected at the approach to Dunkirk Harbour, but expressed a doubt whether the results would be equally satisfactory in Liverpool Bay. He explained that his reason for adopting diverging training-walls in his experiments was that converging walls in Liverpool Bay would involve an enormous expense, but added that these converging walls would certainly be preferable. He said, "There is no doubt, as amply proved by the results of scheme A in the Seine experiments, and by the experience of the effects of converging walls at Dublin Harbour and elsewhere, that walls converging on the bar would deepen the channel over the bar. The wall or embankment, however, on the western side would constitute a gigantic work, about 7 or 8 miles in length, and traversing deep water for some distance; and both walls would be fully exposed to the sea." The opinion of Mr. Vernon-Harcourt on the action of converging breakwaters was worth recalling, for it would be found that these converging breakwaters always afforded great depths, as illustrated by the new experiments made at Rouen on the model of the Seine. As stated in his (Mr. de Coene's) pamphlet of 1890, Mr. Vernon-Harcourt's experiments were to be repeated by the Government engineers at Rouen with a larger model. These experiments had been commenced at the end of 1890, and were now in operation; and he had become convinced, by an examination of the model, that the adoption of a scheme with a narrow neck would afford a depth of 21 feet from Tancarville to the outlet between the breakwaters. The depth increased in an outer roadstead of 7,500 to 10,000 acres, where, over a large area, it amounted to 50 feet below

¹ "Étude sur les Expériences de M. Vernon-Harcourt, et le Congrès Maritime à l'Exposition," J. de Coene, 1890, p. 11.

² Proceedings of the Royal Society, vol. xlv. p. 514; and "Effects of Training-Walls in an Estuary like the Mersey," 1890, p. 7.

Mr. De Coene. low water. A shoaling occurred some distance from the outlet, forming a bar which, however, did not rise within 26 feet of the zero of the charts. As the sea very rarely fell below this zero, the Seine would be accessible at all times to vessels drawing over 26 feet of water. Moreover, the employment of powerful dredgers, like those at work on the Mersey bar, would enable the bar to be lowered, and the channel between the walls to be deepened, so that vessels could get up as far as Tancarville at low water. A deep roadstead would thus be provided in the Seine estuary, where the naval and commercial fleets would find a safe and efficient refuge. This was the scheme which he had already advocated in 1886 and 1889, and which had now emerged from the region of speculation. It might be expected that the official results of these experiments would be soon published, and that the solution which he advised would be carried out; and the Port of Havre would thus be accessible, by a new entrance into the Seine, at all times to vessels of 28 feet draught, like the Scheldt from Flushing to Terneuzen, and the Maas up to Rotterdam. The navigation also on the tidal Seine up to Rouen would be assured at every tide, as in the most favoured ports of the world. Accordingly, it was now certain that the project to be adopted should consist of a breakwater starting from Villerville, and stretching out to the Amfard bank; the training-walls also should widen out from Tancarville to a width of 4,290 feet opposite Honfleur, instead of 1,970 feet as proposed in Mr. Partiot's project of 1859, and the south training-wall should be prolonged to the Amfard bank, an opening being left at the outlet of the Seine into the sea, 8,860 feet in width. The enclosing breakwater might be formed of fascines, as employed on the Weser, and at the jetties at the mouth of the Maas, which would enable it to be constructed cheaply, rapidly, and solidly, and thus ensure the creation of a roadstead in the Seine estuary of great depth and with a fixed channel.

One point had not hitherto been dealt with by the engineers who had discussed the subject, namely, the way in which the works should be carried out. Mr. Caland, the eminent engineer of the River Maas improvements, had remarked to him that the works for the completion of the improvements of the Seine should not be carried out like the works above. In an estuary like the Seine, the works, at the point they had reached, should not be extended from above downwards, as in the upper part of the river, but from the sea upwards, as had been done on the Maas, where the cut across the Hook of Holland was undertaken first, and also on the Tees in constructing the breakwaters on the sea-coast. Having

first fixed the outlet of the river, the interior works would be carried out much more easily and cheaply; whereas in proceeding from above seawards, almost insuperable difficulties would have to be overcome. Moreover the partial closure of the mouth of the Seine was justified by the tradition which indicated that the Seine estuary was formerly deep and stable as far as Harfleur, at a period when the outlet was closed between Villerville and Ratier by a tongue of land covered with trees, for at low tide traces were found in this part of the remains of an ancient forest, showing that in ancient times the Seine had not as large a mouth as at the present time. This bore out the schemes which he and Mr. Le Brun had advocated in the discussion at the Société des Ingénieurs Civils in 1886 and 1889, and which Mr. Partiot had proposed in 1859, but with insufficient widths for the easy admission of the flood-tide. The estuary of the Seine thus enclosed would form a vast roadstead at its entrance, where the flood-tide spreading over a large area and providing a large volume of water at high tide, would furnish the vast reservoir which Mr. Wheeler considered necessary for the maintenance of the entrances of tidal rivers. The new widening-out between the training-walls, in accordance with the opening left at the outlet into the sea, would thus afford a continuous enlargement of the channel out to sea, facilitating the introduction of the flood-tide into the river. The results, accordingly, asked for in the discussion on this subject at the inland navigation congresses, at this Institution, and at the sister society in France, would be realised.

BARON QUINETTE DE ROCHEMONT considered it was unquestionable that the depths in a narrow neck were relatively larger in most cases, as this was the natural effect of any narrowing of a current; but these depths only extended a certain distance below and above, beyond which they shoaled in proportion to the local conditions, so as almost always to form a bar. The depth of water on this bar was generally much less than in the neck, and in many cases too little for vessels to enter the river at all times. Though there was a minimum depth of 40 feet over the bar of the Gironde, and 28 feet over the Humber bar, on the other hand, at the entrance to the Loire, the depth over the bar at low water was only 11 to 13 feet, and in front of the Tagus only $19\frac{2}{3}$ feet. The important question, therefore, for navigation was not the depth in the neck, but the depth over the shoals below. A study of the maritime charts showed that a number of rivers with a neck had only small depths at their mouths, as, for instance, the Loire, the Adour, the Liffey, the Senegal, &c. On the contrary, many rivers with funnel-shaped

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Baron Quinette
de Rochemont.

Baron Quinette
de Rochement.

outlets possessed great depths at their mouths, as, for example, the St. Lawrence, with a minimum depth at low water of 330 feet, the Thames with a minimum depth of 27 feet over its bar, the Forth with 88 feet, and the Congo with 164 feet. The analogies cited were often misleading, for rivers almost always exhibited contractions followed by expansions near their mouths; and they were, therefore, liable to be classed as estuaries with a neck, or funnel-shaped, according as they confirmed or not the theory put forward. Special attention should be paid to local conditions, which varied so much in different rivers; and therefore he could not admit the comparison, instituted by Mr. Partiot, between the Foyle and the Seine, whose conditions were absolutely different.

The waters of the Foyle were clear, carrying no alluvium along; and all the prevalent winds were in the opposite direction to the entrance to the bay. The mouth of the Seine, on the contrary, received all the drift from the sea, for the flood-tide, whether coming in from the north or south, was densely charged with materials, and the prevalent winds blew right into the estuary. Moreover the currents in front of the Foyle flowed transversely to the neck, instead of converging from all sides towards the mouth, as in the Seine. The little counter-current, caused by the projection of Cape Inishowen to the east of the neck of the Foyle, was merely a local peculiarity, which could not be compared to the reverse current occurring in the northern part of the mouth of the Seine, at the moment the filling of its estuary was completed.

The construction of a breakwater in the estuary of the Seine, connected with the southern shore near Villerville, would seriously disturb the *régime* of the currents and the tides. The current passing along the coast of Calvados, and continuing its easterly course till high water, would be diverted northwards; and the reverse current would occur sooner, would increase in strength, and would arrive in front of Havre more charged with sediment. There, meeting with currents flowing in other directions, eddies would be formed, causing loss of velocity and the formation of shoals in front of the neck. The filling, also, of the Seine and its estuary would take place under conditions difficult to foresee, since it should be effected by the waters which actually flowed northwards about an hour before high water at Havre. The rise of tide in the Seine might be diminished; the water would attain a higher level in the south than in the north of the estuary; and it was likely that the second high-water would cease, to the great detriment of navigation. Moreover, the flood-tide, laden with sand collected from the banks below, would bring materials into the

estuary, which would be deposited at slack-tide, and would accumulate in the sheltered recesses, from which it would not be displaced by the ebb. The capacity of the estuary must be thus gradually diminished, to the great detriment of the depth over the bar, which would be formed below the neck. The port of Trouville, also, would be irretrievably destroyed, and the port of Honfleur would run a serious risk of a similar fate.

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de Rochemont.

It had been stated that the shoal below the neck, if it was formed, would be situated where the depth of the water was great, and therefore could not be any impediment to navigation. Undoubtedly the shoal would form in a position where at present there was a fairly considerable depth at low water; but probably only a relatively short time would elapse before the shoal was sufficiently raised to form a serious obstacle to navigation. The Seine bank, indeed, which stretched out to sea in front of the mouth, furnished an inexhaustible supply of sand; this bank supplied the 460,000,000 cubic yards of sediment which had been deposited in the estuary in a few years; and from this bank would come the alluvium which would form the new shoal. It would be impossible to state beforehand the precise height that the bar would attain; but there was every reason to fear that the depth over it at low water would be inadequate for the free passage of vessels at all states of the tide. In fact, such a depth was rarely found in rivers more favourably situated as to tides and alluvium than the Seine.

The project, accordingly, proposed by Mr. Partiot for the improvement of the outlet of the Seine was of a most risky character. This conclusion had, moreover, been confirmed by the results of experiments with small-scale models of the Seine, made first by Mr. Vernon-Harcourt, and subsequently by Mr. Mengin-Lecreulx. On the contrary, the improvement of the outlet of the Seine could only be effected by facilitating and regulating the influx of the tide, by means of training-walls widening out rapidly, and by lowering the shoals existing in the channel.

Mr. L. L. VAUTHIER remarked that the laws governing the motion of the waters on the surface of the globe were everywhere identical, with only those modifications which differences in cohesion and density might introduce. In spite, however, of this absolute identity, the diversities in surrounding conditions, and variations in the numerical factors exercised such an influence on the phenomena, that at first sight, especially in regard to the complicated case of the outlets of tidal rivers, each appeared to constitute a special problem. The variety in the numerous physical conditions

Mr. Vauthier.

Mr. Vauthier. affecting the mouths of tidal rivers gave to each tidal outlet its special features, which authorised regarding with suspicion a system which was supposed to be applicable to all tidal outlets without distinction. He would admit that the restricted outlet, advocated by Mr. Partiot, might be adopted with advantage, within reasonable limits, for the mouths of tideless rivers, and might even be expedient for rivers with a large fresh-water discharge, flowing into seas with a small tidal range, provided that each case was separately considered. Where, however, owing to a great rise of tide, the most potent factor in the maintenance or creation of a good navigable depth in the river was the volume of tidal water introduced by the flood-tide and expelled by the ebb, it appeared to him difficult to allow that it could be expedient to make the flood-tide first pass through a narrow neck to effect an improvement. This was the sole point which he proposed to consider; and as Mr. Partiot specially proposed to apply this theory to the Seine, he would take the mouth of the Seine as the basis of his argument. At the close of his Paper, Mr. Partiot acknowledged that the increase of the volume of the flood-tide to its utmost limits in ascending a river was advantageous; and so far he (Mr. Vauthier) entirely agreed. Mr. Partiot, however, added that the divergence in opinion between him and his opponents, as to the form that should be given to mouths, was partly due to their not having sufficiently taken into account the fact that the progressive increase of the sectional area of the channel was of far greater importance for the free influx and efflux of the tide than its increase in width. Although the introduction of tidal water into a river, followed by a partial driving back of the fresh-water discharge, was a purely hydraulic phenomenon, rather than the propagation of the tidal wave, he would nevertheless be disposed to admit with reservation Mr. Partiot's statements on this point, whilst noting that partial contractions of a river always produced injurious losses of momentum. Where, however, was the progressive increase of sectional area on which Mr. Partiot relied? It was expedient at this point to put aside vague general affirmations, and to examine in detail a particular case, as he would do in the case of the Seine. The general condition of the Seine estuary had been described in various publications.¹ The systematic regulation of the banks,

¹ "Rapport sur les Améliorations dont sont encore susceptibles la Seine Maritime et son Estuaire," L. L. Vauthier, Rouen, 1881; "La Seine Maritime et son Estuaire," E. Lavoinne; and Minutes of Proceedings Inst. C.E., vol. lxxxiv. p. 241.

and the dredging of shoals carried out above Quillebeuf since Mr. Vauthier, 1880, had increased the tidal volume, and diminished the drop of the high-water line between Quillebeuf and Rouen; but the desirable widening of the trained channel, to which the raising of the high-water line of spring-tides below Quillebeuf and its depression above were attributed, had not yet been effected.

The scheme of improvement proposed by Mr. Partiot was shown on Fig. 4, Plate 4, and consisted in prolonging the existing training-walls without increasing the width between them, and in reducing the outlet to a width of about 2,190 yards, by a break-water extending from Villerville towards Havre, with a bend seawards towards its outer end. Was this outer portion to be continuous as shown in the scheme of 1887, or was an opening to be left in front of the present entrance to Havre as shown on the plan accompanying the Paper; and was the low training-wall, prolonged from La Rille, to stop at Honfleur, or to extend towards Havre? These points, however, were only of secondary importance; and his chief concern in the present instance was the question of the filling of the estuary by the tide.

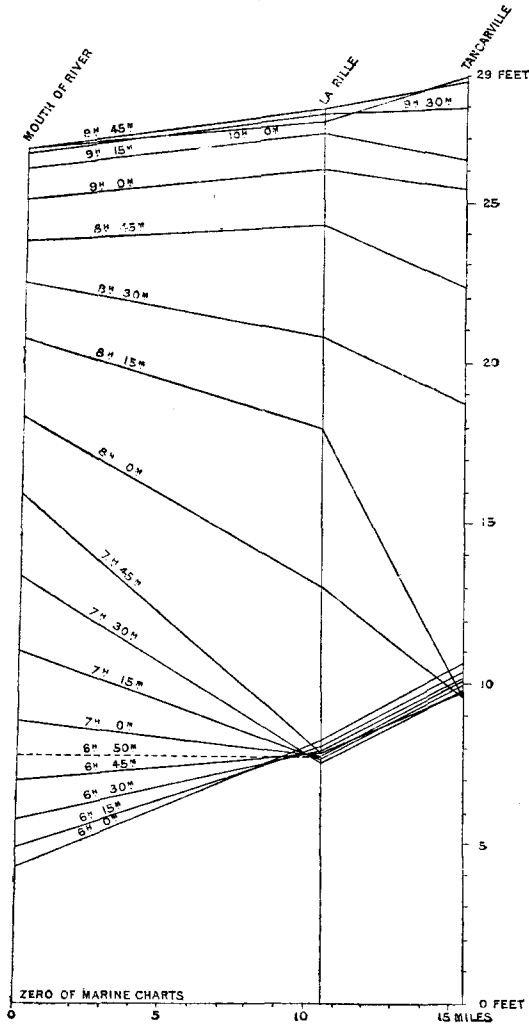
The volume of tidal water entering the trained channel at La Rille depended essentially on the conditions of the filling of the Seine estuary up to that point, and had little relation to the laws of the propagation of the tidal wave. The estuary, strewn with sandbanks, between which the ebbing waters flowed away through winding channels, was an empty space filled by the rising tide; and though under the existing conditions of two branch tidal waves, from the north and south respectively, combining to fill the estuary, it was possible that the final influx of water into the estuary might experience feebly the rhythmic influence of the tidal wave passing along the southern coast, it was certain that, when once the estuary was barred, this kind of influence would cease entirely. There would only be an immense receptacle communicating through a neck with an infinite mass of water subjected to a definite tidal oscillation; and the first question was how the estuary would be filled through this neck, previously to the changes which the new works might produce. The volume of tidal water flowing at each tide into the estuary in 1875, was stated in his report of 1881 to amount to 906,000,000 cubic yards during an ordinary spring-tide, and 433,000,000 cubic yards during an ordinary neap-tide; and he also obtained, for the preparation of the same report, observations of the spring-tide of the 20th of September, 1880, and of the neap-tide of the 27th of September, 1880, taken at Havre, La Rille, and several other stations on the

Mr. Vauthier. river. To compare the cross-sections at the outlet at different heights of the tide, under existing conditions, and as modified by Mr. Partiot's scheme, he had adopted the meridian of Villerville for the present outlet, to be well within the mark; and he had assumed that the depth in the neck would be $16\frac{1}{2}$ feet below zero at the sides, increasing to 41 feet in the centre, and exceeding 33 feet for a width of over 1,250 yards, which depths could hardly possibly be exceeded. Under these conditions, the cross-sections of the outlets increased between zero, or the lowest low water, and high water at springs, $26\frac{3}{4}$ feet above this level, from 32,120 to 114,990 square yards in the present estuary, and from 23,920 to 43,420 square yards in the proposed neck; whilst the ratios of the sections in the estuary to those in the neck increased from 1.343 at zero up to 2.643 at high water. Beginning with spring-tides, which evidently should give the most characteristic results, the tidal rise every quarter of an hour at Havre, La Rille, and Tancarville on the 20th of September, 1880, were indicated in the diagram, *Fig. 15*.¹ The diagram showed that, at the time of low water at the mouth, the tide was ebbing with a considerable slope from La Rille to the mouth; and as the tide continued falling at La Rille till seven o'clock thirty minutes, when the tide was 5 feet $10\frac{1}{2}$ inches higher at the mouth than at La Rille; and, under these conditions, the tidal lines between La Rille and the mouth during those periods were clearly not straight but concave. In any case it was reasonable to assume that till the tide outside reached a height of 7 feet $7\frac{1}{2}$ inches, represented by a dotted line on the diagram, the tidal current had not been reversed at the mouth, and that the estuary had not received any appreciable quantity of tidal water. The rise of tide from this level to high water, amounting to 19 feet $1\frac{1}{2}$ inch, was effected in two hours fifty-five minutes; and the mean rate of rise every five minutes during this period was $\frac{19 \cdot 12}{35}$ feet = 0.546 foot. The mean sectional area of the existing outlet between these heights was 82,860 square yards; and as 906,000,000 cubic yards had to flow in during the period of ten thousand five hundred seconds, the average velocity was $V = \frac{906,000,000 \times 3}{82,860 \times 10,500} = 3.124$ feet per second. After six o'clock

¹ Besides the diagram, Mr. Vauthier's communication contains three numerical tables, the main results of which have alone been given, owing to want of space; and the length of the communication has rendered considerable condensation necessary in other respects.—SECRETARY INST. C.E.

fifty minutes, the fall towards La Rille remained fairly regular Mr. Vauthier. through seven-tenths of the total rise; and the most natural hypothesis was that the velocity of influx varied in proportion to

Fig. 15.



the rate of the rise of tide. As the most rapid rise in five minutes was 1.14 foot, or very nearly double the mean rate of rise, it followed that the maximum velocity of influx was 6.25 feet per

Mr. Vauthier. second, which did not appear excessive. These data enabled the depressions of levels that would occur in the estuary from the influx of the tide through a narrow neck to be calculated, from which results it appeared that with a spring-tide corresponding to that of the 20th of September, 1880, the maximum depression of $2\frac{3}{4}$ feet would take place at about half-past seven, at which time the velocity of flow through the neck would reach $13\frac{1}{4}$ feet per second, and that for less than a quarter of an hour during the rise after six o'clock fifty minutes would the depression be less than 9 inches, and the velocity of influx in the neck be less than $6\frac{1}{2}$ feet per second. Similar calculations, on the same basis, having been made for a neap-tide corresponding to that of the 27th of September, 1880, with a range of only $7\frac{2}{3}$ feet, indicated that the depressions of the water-level in the estuary due to the neck, and the velocity of influx through the neck, were comparatively very slight in this case, reaching a maximum of not quite 2 inches of depression, and $3\frac{1}{4}$ feet per second velocity of flow. Though the contrast in these respects between springs and neaps was very great, it was only the result of well-known laws.

The calculations of depression due to the neck assumed that the inflowing water started from a state of rest; but this hypothesis was not in conformity with the facts under existing conditions. The velocity of influx could not be created without some surface-depression; but this depression, which for the average velocity of $3\frac{1}{10}$ feet at spring-tides did not exceed $1\frac{1}{3}$ inches, began in the meridian of La Hève, more than $2\frac{1}{2}$ miles to the west of the meridian of Villerville, where the outlet was assumed to be; and when the entering waters traversed this, they had already received their impulse from the ocean, and did not undergo any fall there. This, however, was not so in the case of the neck. Formerly, when Mr. Partiot proposed to place the new mouth close to Havre, it might have been supposed that, at the first moments of the rise of tide, the waters would have approached the neck with an already acquired velocity, though extremely feeble and producing only a very slight effect. Nothing analogous, however, could occur now, even for this brief period, when the new mouth was under La Hève, right on the open sea; and in any case this was incontrovertible with still water, which the estuary had to draw upon to fill itself very soon after the beginning of the rise, when the branch of the flood-tide coming from the neighbourhood of Trouville would be stopped by the breakwater. The calculated depressions, therefore, were decidedly effective quantities, in which a coefficient higher than unity might clearly have been intro-

duced, in accordance with admitted facts relating to the flow of water. Mr. Vauthier.

To complete the investigation fully, it would be necessary to calculate in stages how the estuary would be filled under the new conditions created by the neck, and especially how the inflowing water would reach the extremity of the trained channel at La Rille for ascending the river; but for his present object some general indications would suffice. At six o'clock fifty minutes the water-level was 7 feet $7\frac{1}{2}$ inches above zero, both at the mouth and at La Rille, *Fig. 15*, the outflow slackened at the mouth, and the filling of the estuary was about to commence; and, supposing the neck suddenly formed, what would be the result? Assuming that the rate of the rise of tide was uniform, a difference of water-level would be formed at each end of the neck as the tide rose, which would increase till it became large enough to remain constant. Calling H the height above the line of departure at which this result was reached, the average velocity of influx during this first period would be exactly two-thirds of its uniform value above H ; and, admitting that the inner level had risen this same fraction of H , the amount of fall would equal $H \div 3$. The variation in the rate of rise modified the simplicity of this conclusion; but these variations altered very slightly the numerical result, if the sole ratio of the sections taken corresponded to the height $\frac{4}{3}H$, a value to which a velocity equal to two-thirds of the average velocity of influx corresponded. Calculating on this basis with respect to the tidal influx due to the rise of $5\frac{2}{3}$ feet, comprised between the levels 7.61 and 13.26 feet above zero, which was about one-third of the total rise above the lower level, the loss of height was found to amount to $9\frac{1}{2}$ inches, equivalent to about 14 per cent. If instead of stopping at the level 13.26 feet, the layer of water taken into consideration had been carried up to 14.40 feet, thereby including in it the greatest rate of rise of 1.15 foot in five minutes, the depression would have amounted to 11 inches, involving a corresponding loss of inflow. These results, though somewhat striking, had been greatly reduced in amount by substituting mean rises for the actual irregular ones, since, taking this into account, at the time of the greatest rate of rise of tide there was a loss of 40 per cent. at this period, when the inflow was most active. The introduction of a neck at the outlet of the Seine would accordingly lead to two grievous results, namely, depression of the water-level inside the breakwater, and loss of tidal volume entering the estuary. The depression would, on the average, be more than $1\frac{1}{2}$ foot up to about nine o'clock, *Fig. 15*, at which time

Mr. Vauthier. the slope of the water-level in the estuary had become reversed, and sloped seawards, and the velocity of influx was slackened at La Rille, producing the rise in the water-line there which was observable near high water. The loss of tidal water entering the estuary, resulting merely from the circumstances considered above, would amount to more than one-fifteenth of the tidal capacity as calculated in 1875, or over 60,000,000 cubic yards; whilst the long period of high water at Havre after nine o'clock could not make up the deficiency, since at this period no more influx took place.

These conditions at the outlet of the neck would necessarily be reproduced at La Rille, which, in spite of Mr. Partiot's low training-wall in prolongation of the outer one, would still remain the real entrance of the river in his scheme. Reduction in the volume passing up, and a smaller tidal impulse were the inevitable consequences; for it would be impossible to obtain as large a discharge through the estuary with gentler surface slopes and a smaller volume of water. This impossibility would be still more manifest if the not inconsiderable loss of momentum, resulting from the abrupt changes of velocity in the current on emerging from the neck, were taken into account. The condition, therefore, thus created, would be extremely unfortunate for the tidal Seine; and as the effect in these cases always reacted upon the cause, the situation would before long become disastrous. Hitherto, indeed, he had only examined the filling of the estuary; but there was no prospect of the neck having a compensating influence on the outflow. Undoubtedly after a certain period of the ebb, the neck would afford an ample section for the efflux; but at the beginning of the ebb, when the estuary was nearly full, an obstruction to the outflow causing a depression of level, the reverse of that noted for the flood-tide, would produce a longer stagnation of the tidal water inside, and increase the amount of sediment deposited, without having any beneficial influence on the level attained, and on the volume of water expelled. The impediment, accordingly, offered by the neck to the influx of the flood-tide would be wholly injurious. The volume of tidal ebb and flow was, as acknowledged by Mr. Partiot, the great factor; and the effects of its reduction, though possibly gradual, would be certain; and without considering the other objections to the scheme, such as the difficulties of execution, and the formation of a bar outside, the immediate advantage upon which Mr. Partiot relied would be liable to disappear. Undoubtedly the first result of the formation of a neck should be a deepening within it, if the bottom could be scoured; but to what extent, and in what manner would this deepening

be extended outside as well as inside? Mr. Partiot had, indeed, Mr. Vauthier. indicated this in the illustrations accompanying his publications; but these anticipations could not be regarded as possessing any definite certainty. Moreover, should they be correct at the outset, if the effects he (Mr. Vauthier) had attributed to the construction were real, the benefit would be lost before long.

In order to justify his schemes for the Seine, Mr. Partiot relied upon analogies which he (Mr. Vauthier) would briefly consider, though he objected to this method of reasoning with regard to tidal outlets. In a very interesting review of the hydrographical conditions of the mouths of large tidal rivers, to which new examples were added in every fresh publication, Mr. Partiot put forward as the most conclusive analogies, the Gironde, the Loire, the Tagus, the Mersey, the Humber, the Foyle, the Maas, the Scheldt, and the Rio Grande do Sul. If it was true that the contraction caused by a neck could not fail to produce a lowering of the water-level at the entrance to a river, and that, in spite of the advantages attributed to this contraction, this depression was in itself a disadvantage, which appeared to him difficult to dispute, then the amount of the contraction and the tidal range were the principal factors in the results. For relatively equal depths, the proportion R of the restriction, either in a natural neck, or in a neck to be made, was a measure of the difference which this restriction produced between the free tidal influx and what might be termed the forced tidal influx. It might be supposed that a contraction of one-half might double the depth of the entrance channel; but it would be difficult to admit that a contraction of four-fifths would increase the depth five times. The factor R , therefore, it seemed to him, should enter as the first power into the comparison to be made between the several cases. The range of tide was one of the elements of the velocity of influx; and the mean value, V , of this velocity was in reality determined by the volume of inflow, and the average section of the entrance channel, which necessarily bore a certain relation to one another. Assuming this relation to be constant, which was favourable to small ranges of tide, and that the duration of the flood-tide was the same everywhere, that the velocity, V , was proportional to the range, and the resulting height to the square of the velocity, then the product RV^2 (RH^2 , where H was the range of tide which, according to the hypothesis, always bore the same ratio to V) furnished a sort of module measuring the obstacle presented by the neck to the action of the tides. Putting aside the Mersey, which was quite a special case, and omitting the Maas and the Rio Grande do Sul, which did not appear to possess

Mr. Vauthier. contractions, the following were the values of RH^2 for the examples quoted by Mr. Partiot :—

Name of Estuary.	R.	H.	RH^2 .
Seine	0·75	Feet. 23·6	418
Gironde	0·50	15·9	126
Loire	0·45	15·6	109
Tagus	0·80	12·0	115
Humber	0·35	18·7	122
Foyle	0·83	6·6	36
Scheldt	0·22	13·9	43

The highest modules after the module of the Seine, namely, those of the Gironde, the Humber, the Tagus, and the Loire, were only between one-third and one-fourth the module of the Seine with Mr. Partiot's proposed outlet, even on the assumption that the rise of tide took place, as at Havre, in less than four hours, instead of about five hours. Consequently, the lowering of the water-level due to the neck, which had been found to average 1·2 foot for the Seine, would be only 0·4 to 0·3 foot for the other outlets, compared with the water-level with an unrestricted outlet, which established a most important difference between examples which Mr. Partiot regarded as analogous. Moreover, the condition of the Gironde and the Loire, which Mr. Partiot desired to extend to the Seine, was by no means perfect. In spite of the very gentle inclination of its bed, the Gironde was very troublesome to deepen; and it was doubtful whether the works carried out at the Pointe de Grave, not to maintain the contraction, but for protecting the salt marshes of Verdon, were satisfactory; whilst the contraction of the estuary of the Loire between Mindin and St. Nazaire was unfortunately far from having made the Loire a model river. The remaining modules were too small to be worth discussing, whilst the seas into which the Maas, the Scheldt, the Foyle, and the Rio Grande do Sul flowed were almost devoid of a tide; and this fact, irrespectively of the other considerations so ably brought forward by the hydrographic engineer, Mr. Gaspari, at the nautical inquiry of August, 1886, on the schemes for improving the Port of Havre and the passes of the Lower Seine, deprived the Foyle of all value as an example, which Mr. Partiot was accustomed to put forward as his favourite instance. It was difficult to see what advantage in

support of his theory Mr. Partiot would derive from the Scheldt, Mr. Vauthier, as well as from the Mersey; for the Scheldt experienced only a very slight reduction in width in front of Flushing; and if the spacious estuary extending about 11 miles beyond was to be attributed to this contraction, it afforded little recommendation to the system of contracted outlets. Liverpool was situated on a narrow neck of the Mersey separating two estuaries, the inner one of which was not suitable for navigation; and the outer estuary which stretched $12\frac{1}{2}$ miles seawards, was intersected by a number of channels, the deepest of which was impeded by a bar with a depth over it at low water of barely 10 feet, and which did not improve. If the tide at the mouth of the Mersey had not a range of nearly 30 feet, the Port of Liverpool would be in a critical condition, as English engineers admitted, and it furnished cause for anxiety; and it was, therefore, surprising that the Mersey had been cited on behalf of the theory of narrow necks.

Many important elements had been omitted from the preceding considerations, such as the inclination of the river-bed, which was generally small near the sea, and the more or less powerful and regular discharge of fresh water. The small rise of the river-bed inland was the most important factor in the good tidal scour of the Scheldt and the Thames. Thus the tidal rise of springs at London, 50 miles from the sea, was $4\frac{1}{4}$ feet greater than at the mouth of the Thames; and the tidal rise at Antwerp, 62 miles above Flushing, was about the same as at sea. The Gironde enjoyed a similar privilege, for at Bordeaux, 59 miles above the Pointe de Grave, the tidal range was similar to that in the open sea; and this circumstance furnished a better explanation of the relatively good condition of the Gironde than the contraction at its mouth. A more thorough investigation, including the discharges of fresh water, would probably exhibit new elements for a rational discrimination; but he, nevertheless, considered that the tidal oscillation remained the main basis of a classification which upset the theory which Mr. Partiot had wholly built up on the simple differences in plan of the mouths. River mouths at which the rise of tide exceeded 13 feet were not numerous; they were chiefly found in Europe, and only along moderate lengths of coasts. This amount of rise occurred only in a few places between Gibraltar and Brest; but it was found between Brest and the Scheldt, from the Scilly Isles to Aberdeen, with the exception of Poole, cited by Mr. Partiot, and near Yarmouth where the rise was only 5 feet; and along the west coast of Great Britain, up to half-way between the Mersey and the Clyde. Along the whole of

Mr. Vauthier. the west coast of Africa, there was only one place, in latitude 12° north, and on the east coast only in the Mozambique channel, and near Zanzibar, where the rise of tide of 13 feet was exceeded; and throughout the coasts of Asia, there were only isolated places where a large tidal rise occurred, such as north of Bombay, on the east coast of the Bay of Bengal, and Corea. On the coasts of America, there were very large rises of tide on the Atlantic coast at the two extremities, namely, in the Bay of Fundy and at Patagonia, with only two places along the intervening coasts where the rise slightly exceeded 13 feet, namely, near Boston, and Maranham in Brazil; and along the west coast of America, the tide rose high only at Cape Horn and a few other places. This summary indicated the parts of the world where examples of rivers with a good tidal rise at their mouths should be sought, which, if he was right, exercised a classifying influence on rivers. Such rivers were few in number, and formed a well-defined class requiring special treatment. Their mouths should be formed so as to facilitate to the utmost the influx of the tide, which acted spontaneously, like a powerful hydraulic ram, when once admitted, and which had not hitherto by any means been utilized to its full extent. These tidal waters entering an estuary were only useful if they also flowed out again, and deepened the navigable channel; but the channel of the ebb was by no means formed in the same manner as the best channel for the influx of the flood-tide. These kinds of outlets, accordingly, involved the solution of a double problem, namely, the creation of two distinct channels closely combined, one the flood-tide channel admitting freely the incoming tide, and the other the ebb-tide channel concentrating in itself as much as possible the out-flowing current. This difficult problem had never been fully investigated, and even then would only admit of partial solutions; but Mr. Partiot's theory had not advanced its accomplishment.

Mr. Vernon-Harcourt.

Mr. L. F. VERNON-HARCOURT, in reply to the correspondence, observed that Mr. Amor had referred to the property of sea-water, and, indeed, other saline solutions, of causing earthy matter to deposit much more readily than was the case in fresh water. Mr. Amor, however, had apparently not discovered the original account of the experiments referred to, which was contained in a report by Mr. Sidell, assistant engineer on the Mississippi survey, dated 1839, and published as an appendix in Humphreys and Abbot's "Report on the Mississippi River." The somewhat anomalous result was probably due to saline solutions producing an aggregation of clayey particles, and, consequently, promoting their rapid pre-

cipitation. The subject was of considerable interest with reference to the formation of bars at the mouths of delta-forming rivers, and was worthy of further investigation. Mr. Vernon-Harcourt.

The particulars as to the proportion of matter rolled along the bed of the Mississippi, objected to by Mr. Corthell, were derived from an article on the Mississippi by General Abbot, published in *The Encyclopædia Britannica* in 1883, and not from documents which appeared prior to the construction of the South Pass jetties. If, as stated by Mr. Corthell, the sediment was carried wholly in suspension in the current, the physical conditions were to that extent less unfavourable than he had supposed, and the improvement of the outlet of the South Pass a less difficult work. With regard to Mr. Corthell's criticism of the views expressed in his Paper as to the existing condition and prospects of maintenance of the 30-foot channel beyond the South Pass jetty channel, he need only quote a paragraph from the "Report of the Chief of Engineers for 1893," which he had only had access to subsequent to the reading of his Paper: "The chart of the sea end of jetties shows a gradual growth of the bar, and clearly indicates the early resumption of those conditions which obtained before the jetties were constructed. If it is therefore desirable to maintain the present 30-foot depth of channel through this bar, the early extension of the jetties is patent to any unprejudiced observer. It is possible that the 30-foot channel at the Gulf entrance may be successfully maintained a few years longer by energetic dredging, but it is evident that it will not be a great while before the prolongation of the jetties will become necessary." This statement afforded a remarkable confirmation of the conclusions he had arrived at from a careful study of the yearly charts.

Mr. Luiggi's remark that "it was assumed that the bars formed at river-mouths were produced mainly by the materials deposited by the river itself," could only apply to the descriptions of delta-forming rivers, in which cases the assumption appeared to be justified. In all the other rivers described, the influence of the waves in forming the bars, and the silting up of estuaries by alluvium brought in by the flood-tide, had been very definitely stated. Under the term littoral currents, he included the currents and waves produced by winds, as well as ocean and tidal currents.

He fully agreed with Mr. Caland that the Maas could not be accepted as an instance of an estuary with a narrow neck, as it had been trained in a funnel-shaped form. Moreover, at a very recent visit he had made to the Maas outlet, he had ascertained that the travel of the sand there was mainly from the south, and not from the north as stated by Mr. Partiot, that the groynes

Mr. Vernon-
Harcourt.

along the coast to the north had been constructed merely to prevent the erosion of the coast, and that the bar at the mouth had been removed by suction-dredgers. The present depth of the outlet-channel, and the marvellous development of the maritime trade of Rotterdam, which he himself had witnessed, within the last fifteen years, did not bear out the gloomy views of Mr. Siccamà. Mr. Stierle had given an interesting description of improvements at the outlets of several rivers on the east coast of North America, showing the value of dredging aided in some measure by training-works. The checking of the flood-tide at the mouth of the Adour mentioned in his Paper, to which Mr. Eyriaud des Vergnes demurred, had been gathered from the tidal rises of the Adour given in "Ports Maritimes de la France," and from the very definite statement made by Mr. Pettit with reference to this subject in the correspondence on "Harbours and Estuaries on Sandy Coasts,"¹ in 1882. He had, however, very recently been informed by Mr. Belleville, the present engineer of the Adour, that the tidal data given in the "Ports Maritimes" had been lately found to be incorrect. He understood that the closing of the openings in the jetties, and the lowering of the bar outside the Adour jetties by suction-dredgers, specially designed for such an exposed situation, had been determined on. Mr. Evaristo de Churruca had supplemented the description of the River Nervion in his Paper by some valuable particulars. He had been acquainted with the Ribble estuary, to which Mr. A. F. Fowler had referred, for a number of years, and had inspected it under various conditions of wind and tide. In traversing the extensive sands of the estuary at low water of spring-tides during a high wind, he had never seen any appreciable transport of the sand by the wind, as the sand had not time to dry sufficiently, especially as it was intersected by numerous rills. The observations of Mr. Fowler appeared to relate to the northern foreshore, where, no doubt, the sand was dry enough near high-water mark to be blown inland; and generalizing from this, Mr. Fowler had been led to an exaggerated notion of the drift of sand under the influence of wind alone. If sand was thus blown across the estuary from the south-west, it would gradually fill up the present trained channel, which would thereby be more injuriously affected than a south-western outlet.

Professor Gaudard had proposed to reconcile the conflicting views expressed in the Papers with reference to the most satisfactory method of improving the outlet-channel of the Seine, by

¹ Minutes of Proceedings Inst. C.E., vol. lxx. p. 69.

barring the central outlet between the Amfard and Ratier banks, and providing two outlet-channels, along the northern and the southern shore of the estuary respectively; but he (Mr. Vernon-Harcourt) feared that this solution would not satisfy either Author, and considered that the formation of two navigable outlets would be prejudicial to the depth and maintenance of both, and was at variance with the true principles of improvement of tidal rivers, which should aim at concentrating the tidal scour and fresh-water discharge into a single channel. Mr. de Coene had misconstrued his opinion with reference to converging training-walls in Liverpool Bay, in supposing that he considered "that these converging walls would certainly be preferable." To bear this out, Mr. de Coene had quoted a passage from his Paper on "Investigations into the Effects of Training-Walls in an Estuary like the Mersey," and had omitted a qualifying paragraph which immediately followed the quotation. This paragraph was as follows:—"Moreover, the comparatively narrow entrance over the bar, whilst deepening the bar channel, would check the tidal flow in the 'narrows' and upper estuary, which would affect the outer channel between the 'narrows' and the bar." He had been informed recently by the engineers in charge of the Seine model at Rouen, that, contrary to the statement of Mr. de Coene's, the Rouen experiments, like his own, had given unfavourable results with schemes providing a narrow outlet. Mr. Mengin-Lecreulx seemed to apprehend that the authority of the Institution would be invoked in favour of the scheme which Mr. Partiot's Paper appeared to have been written to promote. The appreciation, however, of the literary merit and trouble in preparing the Paper, extended by the Institution to a foreign engineer of high standing, did not in any way imply the slightest agreement with the views expressed in the Paper; and it would be wholly at variance with the scientific objects of the Institution if this act of courtesy could be used as a means of pushing forward a scheme which had been viewed with distrust by the several eminent engineers who had successively had charge of the tidal Seine. He was in agreement generally with the objections raised by Mr. Mengin-Lecreulx, Baron Quinette de Rochemont, and Mr. Vauthier, to the conversion of the outlet of the Seine into a narrow neck; and he was of opinion that, under the special conditions of the Seine estuary, the contraction of the outlet of the Seine by a breakwater from Villerville to Amfard would reduce the tidal rise inside, and would result in the silting up of the estuary, the formation of a bar outside, and a large advance of the foreshore in front of Trouville.

Mr. Vernon-Harcourt.