Mr. Vernon-Harcourt.

and the wave action tended to heap up the sand upon the western side of the jetties more than on the eastern side. Such a direction, however, would not be favourable to the maintenance of a harbour by sluicing, which was always effected during the ebb.

The difficulty, in a situation such as Dunkirk or Ostend, of introducing the system of an outer breakwater connected with the shore by an open viaduct, consisted in the small depth of water attainable near the shore and the exposure of the straight line of coast. The establishment of a breakwater on an outlying sandbank might lead to an extension of the sandbank, as had happened at Calais; and the more the shelter provided between the breakwater and the shore the more it would favour the deposit of sand brought along by waves. He considered that the best prospect of maintenance on such a flat sandy coast would be to form the harbour with solid piers, starting from the shore at some distance apart and converging at their extremities, which should be carried into as deep water as practicable. If circumstances admitted of a choice of site, it should be selected where a good depth of water approached nearest to the shore, and where the piers would project most beyond the adjacent coast so as to secure a scour across the entrance.

Correspondence.

Mr. Russel Aitken.

Mr. Russel Aitken believed it would be found cheaper to treat some harbours by means of short jetties, and a considerable amount of continuous dredging, or by continuous dredging simply, without jetties. At the harbour of Calais the chief engineer had shown him the plans of the dredging which had been carried out since June 1881. The bar had been reduced by 5 feet in height, and there could be no doubt that the depth of 10 feet at low water, which was aimed at, would be attained at very little cost. Some sand was brought along the coast from the westward, and found its way round the end of the west pier. The cost of dredging had lately been much reduced, and in the case of Calais it was contracted for at the rate of 7*d.* per cubic yard. Many works therefore could be more cheaply done by dredging solely than by dredging in combination with piers; although in some cases, such as at the mouth of the Tyne and at Ymuiden, long piers were necessary to shut out the waves and to quiet the water in the harbours.

Kurrachee harbour was an instance where the Manora breakwater might have been dispensed with at the cost of some extra dredging. Of course the breakwater was useful to a certain extent in quieting the water in the harbour; but the sand moving from

Mr. Russel Aitken. the westward had been carried, or would shortly be carried, round the end of the breakwater on to the site of the former bar, where it would be deposited and have to be dredged away. The interest on the money which had to be expended on even a short length of breakwater would pay for a considerable amount of dredging.

Mr. Caland. Mr. P. CALAND furnished some details of the works for the new entrance to the Maas. The scheme for improving the New Maas, and making a cut through the Hoek of Holland, proposed to give the river a funnel shape, following regularly lines with increasing breadth downwards, corresponding with the greater difference between high and low water towards the sea, and consequently with the larger quantities of water that had to be discharged. In order to provide a suitable depth at the mouth, two piers were projected and added to the plan, between which the new river was to debouch, while to increase the discharge, and to prevent the influx of sand from the sea, it was proposed to cut away the easternmost point of the island of Rozenburg. In this way the Old Maas would be led into the Scheur, and be of service in scouring the part of the new river along Rozenburg. In connection with this a gradual enlargement of the new river-bed near Vlaardingen was proposed. The works at the Hoek of Holland were started first. The piers in the sea were built, and the cut through the Hoek made, the latter on a much larger scale than was originally proposed; and as the cutting went on, the old branch, the Scheur, was checked with the object of entirely stopping it as soon as the cutting was sufficiently advanced. In 1871 it was thought the proper time had come for this. The Scheur was completely stopped, and the cut grew wider and deeper from the effect of the stream, so that on the 9th March, 1872, the first ship went out to sea through the new channel. This was the steamer "Richard Young," running between Rotterdam and Harwich. The smallest depth in the new fairway was then about $6\frac{1}{2}$ feet at ordinary low water, and this depth continually increased till in the winter of 1875–76, when it amounted to 13 feet at ordinary low water, and to $19\frac{1}{2}$ feet at ordinary high water. But in the winter mentioned there was a continuance of extraordinarily high freshes (*opperwater*) along with heavy gales, which lasted about two months. This caused not only a great discharge of sand and mud from the rivers, but the action of the tides in the new river mouth was greatly interrupted. There were days on which there were actually no flood tides in the river mouth at the Hoek of Holland. These causes induced silting to a somewhat less depth than $11\frac{1}{2}$ feet at low water; and as it was evident that the cut through the Hoek (only averaging 650 feet wide) was much too restricted in proportion to the width upstream and between the piers, it was determined to enlarge it. This was done, and the cut at present was about 1,640 feet across. As a result of this work the current had become much more powerful, and the water escaped to the sea in a straight line. By this a new channel was now opened southward of the former one in the direction of the cut, and which would certainly be the channel of the future. It was also beyond doubt that this channel would be much deeper if the cut through the Hoek of Holland were made according to the original scheme, that was from 820 to 930 yards wide. The cut was at present being enlarged, but pecuniary difficulties prevented its proceeding with desirable speed. Had the plan been carried out in full no doubt the proposed depth of 23 feet at high water would have been acquired, which was only 3½ feet more than had been obtained once, and would be obtained again. Recent soundings indicated a depth of 13 feet at ordinary low water in the south channel. Mr. Caland.

As regarded the Author's statements, it might be observed that the present mouth of the river was in the same place as the former, which was used when William III. was King of England, and that instead of the bar enlarging towards the sea, on the contrary it was decreasing, so that the contour lines of soundings were extending landwards instead of seawards. The bar was thus scoured away by the flood and ebb tides of the sea, and the surface of the upper levels was also lowered by the same currents. The whole scheme depended on the execution of the plan as projected, and in that case the Old Maas would supply water to the Scheur instead of deriving it thence, as Mr. Vernon-Harcourt supposed. Mr. Caland was more in accord with what the Author put forward on page 279 of his recently published work on rivers and canals than with the contents of the present Paper.

Mr. W. DYCE CAY thought the Paper would be useful in directing attention to scour as the only natural agent for deepening and maintaining harbours on sandy coasts, and in demonstrating the impolicy of embanking estuaries. He was able to corroborate, from his experience at Aberdeen, the Author's statement, that when in such harbours depth had to be maintained by dredging, "every additional increase in depth thus attained increases in a sort of geometrical ratio the amount of material that has to be removed every year in order to maintain it." That result was indeed self-evident, as the increase must go on until the limit of the supply of silt had been reached. Mr. Dyce Cay.

Mr. Dyce Cay. In cases, however, where sufficient scour could not be got, he thought much good might be done by stopping or diverting the sources of the inflow of silt into a harbour. From this point of view it appeared a mistake only to raise the jetties forming the sides of the entrance channel to half-tide level, as in the continental harbours described, and to allow the upper half of the tide, or littoral current, to flow freely over them, as in that state they formed groynes most favourable for collecting sand. On the other hand, when carried above high water, as in the case of the British harbours referred to, the tidal current was generally induced to run seawards along their sea face, which, with the help of the waves, prevented the advance of the low-water line outside them. The small river, which it was proposed to include in the new outer harbour at Boulogne, would also be a source of silt, and would thus cause expense in dredging. In the same connection, he considered that it would have been better if the new outlet of the Maas through the Hoek of Holland had been canalized with locks, like the Amsterdam canal, as in that way the silt, coming from the river and from the sand-bearing tidal sea water, would have been much diminished. At Dunkirk, which he had visited, the sandbanks, the channels of the sea, and the tidal currents, lay parallel to the coast. It seemed that an improvement might be possible by taking advantage of, and developing, this natural tendency, by means of jetties or other works parallel to the coast, similar to the outer part of the proposed enclosing piers at Boulogne. Such works might train a sea-current to run past the mouth of the harbour, and so by scour to effect the work of maintenance now done by dredging.

Commander Cialdi. COMMANDER A. CIALDI approved generally the views of the Author as to the causes of silting-up of harbour entrances, and also as to the conservation and regulation of natural reservoirs for tidal water. But there were some points on which he differed from the propositions set forth in the Paper; as, for example, the depth to which wave-action extended, the Author estimating it at less than was, in his opinion, the case—and the life of closed harbours on sandy coasts. His own experience convinced him that jetty harbours were alone available under such conditions. His views on the subject were contained at length in his competitive essay for the prize offered by the King of the Belgians; but inasmuch as the international jury had not yet made its award he was prevented from enlarging upon them. The subject had for many years received his careful and attentive study, and it was with great pleasure that he found in the Author's communication confirmation of his own opinion, many times expressed, that hitherto the means employed for improving harbours on sandy coasts had not given satisfactory results. He considered that the Paper furnished a complete and just diagnosis of the case, although it left much to be desired in the direction of suggestions for affording a remedy. Commander Cialdi.

Mr. W. J. Doherty thought the Author had bestowed much care and devoted a good deal of attention to a subject which had frequently baffled engineers, and which had caused their plans to be altered almost as often as the sandbanks themselves. Every alteration or projection on a coast-line invariably affected the direction of the currents, and often, even without any artificial projections or indentations, large volumes of sand constantly changed their position, either on account of the more rapid flowing of spring tides, or the effects of periodical storms, which produced in shallow waters nothing but sand-bearing waves; hence the disturbed "equilibrium," attributed by the Author to artificial projections "from the coast," frequently resulted from purely natural causes. Mr. Doherty.

The statement that where a "current is checked by the construction of a jetty across the channel," a deposit in the channel was sure to follow, was a truism. Further, the lengthening of jetties seaward on a flat foreshore, if the jetties were in any part solidly constructed, acted as an obstruction or impediment to the flow of the littoral currents, and entailed as a sure consequence the extension of the beach. It did not seem surprising that jetty extensions were abandoned at Calais after 1845, and that the only effective remedy, the construction of a tidal reservoir or sluicing basin, was now in progress. Although, as shown by the Author, the opinion of Mr. Eyriaud-des-Vergnes at Dunkirk was against sluicing, it was because of the set of the tides; this, and every local circumstance, should be carefully examined and considered, before any remedy was decided upon. But it became serious when it required 350,000 cubic yards of dredging to keep open the channel, costing, as at Dunkirk, near £13,000 yearly.

A striking instance of local alterations in the shifting of sandbanks was at present noticeable in the Mersey at Liverpool, where the great landing-stage had become so affected during recent years by the movement of Pluckington bank, as to cause serious inconvenience from the grounding thereon of the stage, at extreme low water, thus interfering with the passenger traffic of the numerous ferry steamers, plying to and from the Cheshire side of the river. The engineer to the Mersey Board, Mr. Lyster, M. Inst. C.E., had

Mr. Doherty. in progress an elaborate system of sluices, which were expected to deal effectively with the obstruction, although the cost would be considerable.

Increased depth of water at Dunkirk would seem to have produced similar results as elsewhere, viz., a rise in the tonnage, and increased size of vessels. On coast-lines, projections and embayments were frequently associated with encroachments and accumulations. The tide acting continuously on advanced headlands, carried with it the materials of which they were formed, and deposited it in the embayments as self-reclaiming foreshore. The rapid silting up of river-banks and estuaries by alluvial deposit-bearing rivers, when any impeding cause prevented their outward flow, was peculiarly observable during the construction by Sir John Hawkshaw of the Hull Docks in 1864, where 2 inches in depth of silt had been deposited in a single tide, on a portion of the site of the docks over which the ebb tide passed, and from which a clear flow could not escape owing to the progress of the river embankment. In this way in about eighteen months a depth of 15 feet of solid silt had accumulated.

The history of Ostend, from 1662 to 1744, instanced by the Author, was an example of the danger of closing up, or even temporarily allowing a diminution of the head of water required to keep open a channel, and showed that when once a harbour entrance was tampered with, it was next to impossible to restore it.

Numerous artificial channels placed at right angles to the coast-line had become deteriorated. A channel constructed by Mr. Doherty at Holywood in Belfast Lough in 1868, on a flat foreshore, where the sands were not much disturbed except in stormy weather, was rendered useless in a few years through silting up, no reservoir being available for scouring. At Silloth on the Solway estuary, the disaster to the dock caused it to be abandoned as a wet-dock, and the gates removed, converting it into a tidal basin. Progressive silting was the result, requiring considerable dredging.

The entrance channel to the harbour of Maryport, was a fair type of the jetty system, to be compared with some of the harbours brought under notice by the Author. With the exception of a small freshet, the Ellen, flowing through the harbour, the whole of the scouring force available to keep the channel clear of sand was that obtained from a small wet-dock from time to time. A solid stone pier had been constructed, from which was extended to low water a wooden structure of open work from half-tide. The gravel and sand accumulated behind the stone pier, as it was advanced. At present he was constructing, from the designs of

Sir John Hawkshaw, Son, and Hayter, a large wet-dock and basin on the foreshore, adjoining and south of the stone pier. As the new works extended seawards, to the point of commencement of the timber structure, there was an apparent tendency of the gravel and shingle to collect in the angle formed by the junction of the sea embankment against the timber pier. However, the increased area, about 8 acres, of water space given to the harbour by the engineers, would largely augment the scouring power, so that, with a moderate extension of jetty, if required, a uniform depth of water might be maintained. Another example occurred at Workington, where the large quantity of shingle brought down by the Derwent, a river fed from the lake district producing a volume of water almost as great as the fresh water of the Thames, was barely sufficient to keep the channel clear, many of the projections and irregular deposits having to be removed and carried out to sea. Mr. Doherty.

Two of the Author's recommendations deserved attention. One was to extend the system of harbours where they existed, "supplying their own tidal reservoirs," as at Dublin; and the other was to avoid and discountenance "reclamation within the tidal area."

The history of all the harbours under consideration showed a neglect of properly curved training moles, walls, or half-tide erections, placed apart from, and at an angle sufficiently oblique to, the line of channel to enclose a large water space, by especially diverging and directing the flow of the latter half of the ebb, and causing a body of tidal water to act on the bars tending to form across the entrance to the harbour.

As a general summary, the regulation of harbours and of tidal waters by the State, under the guidance of the best qualified engineers, would appear to be a *sine quâ non*. Certainly no erections curtailing water space should be permitted without the consent and advice of a committee of the most experienced harbour engineers, as the protection and extension of commodious harbours should be the first duty of any great maritime power.

Mr. Duckham. Mr. F. E. Duckham believed the objectionable features to which the Author referred, as existing in the new waterway through the Hoek of Holland, were recognised at an early date by Mr. Caland, and in 1877 the Dutch Government decided on spending half a million sterling in carrying out his recommendation, by straightening, widening, and deepening the channel between Maasluis and the sea. This involved the removal of some eight millions of yards of material, about one-third of which was to be dredged and

Mr. Duckham. dropped about 2 miles outside the piers, the remainder to be deposited on the adjacent dunes and polders, and in the little-used river Scheur. The then projected works in the river Maas had since been executed, but the cut at the Hoek of Holland had not obtained the width proposed by the plans of 1858. That width was to have been 750 to 850 metres (820 to 930 yards), but at present it was 500 metres (547 yards) only. A result of this was that the currents in the cut, and those above and below, were not in the right proportion, and the effect on the bar was not so beneficial as it would doubtless be when the full width was obtained. At present there were two channels, one along by the north and one near the head of the south pier. In both the depth was about the same, say 11 to 12 feet, at low water, but the south channel was much wider than the north. The works were still in progress, with proportionately increasing benefit to the navigation of the river.

The works at the mouth of the river Seine, including the Tancarville canal, had already been dealt with in the Proceedings,[1] so that it was unnecessary for him to do more than allude to them.

In reference to Ostend, Mr. Duckham did not understand that the sluicing basin was an entire success. It scoured a pit at its outfall, some 7 or 8 feet below the normal level of the harbour, but its useful effect seemed to be lost long before the water reached the harbour mouth, where its assistance was most required. As an improvement, a line of iron pipe had been laid down, more particularly to direct the sluicing force upon the bar; this was at first successful, but was subsequently rendered inoperative by the sand accumulating therein and completely choking the passage. It had recently been decided to endeavour to increase the depth at low water over the bar by dredging from 7 feet 6 inches to 12 feet, and to maintain that depth within the chief portion of the harbour by similar means. About 200,000 yards were dredged last year by a pair of sand-pumps on a dredger, having a steam-engine of 35 nominal HP. The spoil was deposited by hopper-barges on the Stroom Bank, some 3 miles from land. This machine could only work in comparatively smooth water, and no beneficial effect had been produced on the bar. The King of the Belgians had himself visited Ostend in the autumn of 1881, with the view to promote the improvement of the harbour, and it was expected that extensive operations would be undertaken at an early date.

The relative effects of wind, waves, and tides on foreshores were shown in the case of Gorleston beach, near Yarmouth Haven. The

[1] Minutes of Proceedings Inst. C.E., vol. lxix., p. 443; also *post.*

ordinary run of the tides had little effect upon it, but a gale of a few hours' duration considerably altered its character, increasing or decreasing its extent according to the direction and force of the wind. Similar effects might be witnessed in other localities. Mr. Duckham.

Mr. J. P. GRIFFITH remarked that the Paper under discussion effectually refuted the doctrines advocated in that of last Session on "The Relative Value of Tidal and Upland Waters in maintaining Rivers, Estuaries, and Harbours."[1] From beginning to end the memoir formed a plea for the free admission of tidal water into harbours and estuaries. The history of almost every harbour and river referred to told of the injury resulting from the effects of land reclamation, and the consequent exclusion of tidal water. It was to be hoped that the discussion would solve some of the difficulties which surrounded this important subject, and explain why the jetty system, combined with sluicing, even on a large scale, had proved a failure. Mr. Griffith.

No one who had considered the subject of the improvement of the North Sea ports would deny the great difficulties which beset any work of the kind; nor would he fail to acknowledge the ingenuity and skill which had been displayed in the designs of many of the works executed for the improvement of some of the more important continental harbours. The leading features of these works were similar in nearly every one of the ports on that coast, viz., sluicing reservoirs, with jetties to concentrate the action of the scouring stream.

It appeared to Mr. Griffith that too much attention was paid to displacing the largest possible quantity of sand in the shortest possible time, without considering what was to become of that sand after it had been displaced. It seemed quite possible to have too great a velocity in the scouring stream, and the question was worth considering, To what extent was it desirable that the velocity of the scouring stream should exceed that of the littoral current into which it discharged? Sudden changes of velocity were, he believed, productive of much evil. Sluicing operations were generally carried on at low water, so as to produce the maximum results; and it was just at that time that the littoral currents were frequently least effective, and the incoming tide brought back much of the sand which had been displaced. He believed that too much attention could not be paid to an investigation of the fluctuations in direction and velocity of

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

Mr. Griffith. these littoral currents when considering the question of maintenance of harbour entrances on sandy shores. The system of parallel jetties so generally adopted at the North Sea ports, extending only to shallow depths, seemed to him wrong in principle. The tendency of such jetties was to act as groynes, and make the sandy shore extend outwards, until the sand passed round the pier-heads, when the waves heaped it up in the form of a bar. Extensions were made until the entrance was gradually removed too far from the sluices to be materially influenced by them; and, as a last resource, dredging beyond the piers was undertaken. This must ultimately prove a ruinously expensive remedy. One of the chief objections to the method just described was, that the entrance being placed in such shallow water the sandy bottom was influenced by every on-shore wind, and the temporary improvements resulting from either sluicing or dredging were neutralised, if not destroyed, by a few hours of stormy weather. From a natural anxiety to utilise to its full extent the available sluicing power, the channel between the jetties had frequently been made so narrow that the navigation of vessels entering the port was very difficult, especially where a strong littoral current existed. To obviate this in some degree, jetties were sometimes made slightly diverging, as in the case of the last extension at Ostend. This diverging form was accompanied by the serious objection that it tended to increase the height of the waves running up the channel. If converging piers had been adopted at the mouth of the Maas, as might have been done without much extra cost, greater shelter would have been given to the new channel through The Hoek, the waves entering being reduced by dispersion. There was little doubt that the Author was correct in his opinion that the economy practised in not excavating the new channel sufficiently wide in the first instance had resulted in much injury to the entrance.

Perhaps the most interesting part of the Paper was that relating to the coast of Belgium. Much attention had been given of late years to the question of the improvement of the ports on that coast; and if any need existed to prove the difficulty of constructing first-class ports on the coast of Belgium, no more convincing evidence could be brought forward than that the principal port of the country was situated about 40 miles up a river difficult to navigate, and which for the greater part of that distance ran through a foreign country. Such was the position of Antwerp on the Scheldt, the most flourishing and important port of Belgium. Both banks of the river for 30 miles from the

Mr. Griffith.

mouth were in Holland, so that in case of war between the two countries there would be little difficulty in blockading the port, and almost putting a stop to the maritime commerce of the country. It was not therefore to be wondered at that there should be a general desire to improve the coast ports. How this could best be done was worthy of consideration, and though the difficulties were great, yet Mr. Griffith was inclined to look hopefully at the prospect of improvement. It was well to bear in mind that the Port of Dublin had at one time greater difficulties in the way of becoming a first-class port than any of the ports on the Belgian coast had to encounter at the present day. The tidal estuary of the Scheldt, he believed, played an important part in protecting the Belgian coast from the accumulation of sandbanks, and accounted for deep water approaching the shore near Blankenberghe. It would be well for the Belgian authorities to take to heart the warnings contained in the Paper, and to resist any proposals to regulate the Scheldt which might tend to reduce its tidal capacity, not only for the sake of the port of Antwerp, but also for the protection of the ports on the coast of Belgium. The maritime frontier of Belgium was 42 miles in length, or only one-twentieth part of the whole frontier of the kingdom. Limited as was this coast-line, it presented many obstacles to the formation and maintenance of first-class ports. It formed an almost unbroken straight line destitute of estuaries or bays, the shore being generally low and formed entirely of sand with a gradual slope. Deep water was only reached at considerable distances from land except near the Dutch frontier, and shallow banks generally cut off direct communication with the shore for vessels of even moderate draught, except at or near high water. These shoals, known as the Flemish Banks, formed the great obstacle to navigation in those regions, and they extended almost from the Straits of Dover to the mouth of the Scheldt. Their general direction was parallel to the land with intervening channels of considerable depth, but intricate and dangerous to navigate. The rise and fall of the tide amounted to 17 feet at springs, and 11 feet at neaps; but this was materially modified by the direction and force of the wind as well as by barometric pressure. The directions of the tidal currents off the coast of Belgium were specially remarkable. At high and low water the direction of the current was parallel to the shore, or nearly east and west. At half flood its direction was on-shore, and at half ebb off-shore. This was no doubt in a large measure due to the great tidal estuary of the Scheldt, into which the flood tide set for several hours after the

Mr. Griffith. time of high water at its mouth, while the ebb in like manner continued to flow outwards long after the hour of low water on the coast. The ports on the coast were but three: Ostend, Nieuport, and Blankenberghe. All were tidal harbours with shallow approaches, Nieuport and Blankenberghe being almost exclusively devoted to fishing-boats or vessels of the smallest class. Ostend possessed a large harbour with extensive basins and quays, and great facilities for further dock extension should it be required. A large fishing fleet frequented the port, but Ostend owed most of its importance to the daily mail packet service with England. Of late years the number of passengers carried by this service had shown a steady diminution, due no doubt to the opening of new routes or the improvement of existing services. Unless vigorous steps were taken, a further falling-off must be expected. Much had been done in the hope of improving the port, but without any considerable success. The result of the costly work described in the Paper for the improvement of Ostend could not be regarded as satisfactory. The channel was still shallow and encumbered by sand blown in from the adjoining beach or driven in by the sea, while the bar, a short distance beyond the pier-heads, still formed a dangerous obstruction. No doubt the depth of water over it was from time to time increased by the large volume of water suddenly thrown on it from the sluices, but the next sea-breeze raised waves sufficiently powerful to destroy all the good effects, and the uncertainty of depth at the entrance during on-shore winds practically neutralised the useful effects of the sluices. Depth of water at the entrance to a port was more needful during stormy than in calm weather, and it was just at such times that sluicing operations, similar to those at Ostend, failed. It might be argued that in this particular case not much would be gained by a great increase in depth of water on the bar, as it was in fact rather the Stroom Bank, extending from Nieuport till it joined the shore some distance east of Ostend, which obstructed direct communication with the sea.

From this brief description it would be seen that the present condition of the Belgian ports was anything but satisfactory. What, then, was the remedy? The extent of sea-coast being so limited, he believed that all efforts should be concentrated on the formation of one first-class harbour which would supply the following wants: 1st. A port open to vessels of large draught at all states of the tide. 2nd. A naval station. 3rd. A harbour of refuge. The entrance of such a harbour must be placed in deep water, and in such a position that there might be no difficulty in maintaining the required depth. Bays or estuaries on a coast materially facilitated the construction of harbours, and to estuaries or bays England owed much of the success of some of its largest ports. On the Belgian coast no such natural advantages existed, and it was necessary to enclose the required area artificially. The question of site was one of the most important considerations. Practically there were but four sites worthy of discussion, viz., Nieuport, Ostend, Blankenberghe, and Heyst. The two latter were among the most favoured sites on the coast for the formation of a deep-water harbour, and no doubt a most useful harbour could be constructed at either of those places at a comparatively small cost. At the same time all the necessary accessories of a first-rate port would have to be added, as none at present existed. Nieuport laboured under similar disadvantages without any redeeming features. Mr. Griffith believed Ostend to be the most eligible site for such a harbour, and he thought all efforts should be concentrated there, although the expenditure might at first sight seem large. Among the many advantages which Ostend possessed over the other sites named, the principal was its being already an important port. Its docks and quays were extensive, and it was amply provided with means of communication with the interior of Belgium both by canals and by railways. It was also the packet station of the English mails. Blankenberghe and Heyst would require a large expenditure on quay and dock accommodation in addition to the cost of a harbour, while the existing interests of Ostend would be materially injured. For these reasons, although the apparent first cost of constructing a suitable harbour elsewhere might be less, yet indirectly a much larger expenditure would be involved. The great difficulty in the formation of a deep-water harbour at Ostend, open at all states of the tide, was the presence of the Stroom Bank, situated about a mile from the shore. No doubt a harbour could be constructed, with its entrance in the Inner Road, which would materially improve the depth of water on this bank, by the joint action of the littoral currents and those entering and leaving the harbour, as in the case of the improvement of the bar of Dublin Harbour. Such improvement would, however, be very gradual, and he was in favour of adopting a plan which, if bolder and more costly, would give more rapid and certain results. With this object he would propose the construction of two great piers extending out at right angles to the shore line till they reached depths of about $3\frac{1}{2}$ fathoms outside the Stroom Bank; they would then converge in a direction nearly parallel to the coast, leaving an opening not less than 1,000 feet wide between the pier-heads, Mr. Griffith.

Mr. Griffith. The object of extending the piers to the outer edge of the Stroom Bank was twofold. In the first instance, to place the harbour entrance in such a position that it would be within the influence of the tidal stream ebbing from and flowing into the estuary of the Scheldt, which at present maintained deep water outside the Stroom Bank. The direction of the extreme portions of the piers being almost parallel to the coast would least interfere with its action, and it might reasonably be expected that the projection of the piers so far seaward would tend to intensify its effect. In the second place, the shelter afforded by the extension of the piers beyond the Stroom Bank would allow of dredging that portion of the bank which was enclosed within the piers, an operation otherwise practically impossible, and even if possible of very doubtful utility without the shelter of the piers. Such a harbour would necessitate the construction of piers of an aggregate length of about 22,000 feet. The improvement of the entrance to Dublin Harbour had involved the formation of more than 26,000 feet of piers. Although an expenditure of about £2,500,000 might be necessary, Mr. Griffith believed it would be fully warranted on the grounds of the national importance of the undertaking.

Mr. Keller. Mr. H. KELLER agreed on the whole with the conclusions arrived at by the Author; but he was of opinion that the latter attached too much importance to the action of the ebb tide on a harbour; for harbour basins invariably contained less tidal water than the estuaries of rivers, and as their extent was much less, their ebb was proportionably weaker. Harbour basins would have to be greatly enlarged if the ebb tide were to be made sufficiently powerful to scour the entrance thoroughly and effectually, as it certainly was in estuaries. It might be safely accepted, that wherever the conditions for the formation of bars were present, sooner or later, the entrance of the harbour would be barred, however far the moles might have been extended. The most favourable condition for the formation of bars was the presence of a littoral current (arising from prevalent winds, and influenced by the tidal wave), which kept the particles of sand in a state of intermittent motion. The harbour of Kingstown was most fortunately situated in this respect; there were no travelling sands at the south coast of the Bay of Dublin. Boulogne also enjoyed an exceptionally good position; for the shore sloped down in terraces, and the coast was not a flat sand coast, but consisted of rocks, the cavities of which were filled with sand.

At Ymuiden a change in the shore was already becoming observable, and the bar which was forming at the mouth required considerable dredging only a few years after the completion of the harbour, to maintain the necessary depth of water. If such dredging was to be avoided artificial scouring must be called in aid, and this would only then prove effectual when the sluices were constructed in the vicinity of the mouth of the harbour. Further, it was imperative that the flushing water should not be permitted to discharge suddenly, but be distributed over a period of some time. By such means the dangerous rapidity of flushing would be prevented, and the scour, though less violent, would exercise a more lasting and beneficial influence. With due attention to local circumstances, it would be desirable to wash the sand away immediately after it had been deposited on the bar, and when it was still easily removable. To this end a portion of the harbour basin should be separated as a flushing basin by a third "inner" mole. With a view to reduce the force of the waves in the harbour at high water, this inner mole should be constructed as an open frame jetty, capable of being closed as soon as ebb tide set in. **Mr. Keller.**

Lieut. L. PETIT, of the Belgian Hydrographic Service, begged to present to the Library a copy of his report on the changes of the North Sea coast during the present century. He was firmly of opinion that the ports of Calais, Dunkirk, Nieuport, Ostend, and Blankenberghe represented the type best adapted for the littoral between Calais and the Scheldt. The trestle piers had been constructed on principles approved by long experience of the regimen of the coast, and which nothing of recent occurrence had tended to modify. The existence of those ports would be endangered by the introduction of novelties, such as lengthening the piers or widening their entrances. In the first case the foreshore would follow the prolongation. Dunkirk presented a striking instance of the danger of having piers too long. In the second case, if the entry were made too wide, banks would form inside, which after heavy weather would seriously compromise the navigation. In his opinion, the only possible solution unattended with danger was the establishment of works parallel with the coast line, provided always that they were sufficiently far from low-water mark. In this way he thought that the project to construct a breakwater in front of Ostend (a plan three-quarters of a century old), far from being injurious to the little roadstead, could only result in its benefit, by contracting the flood-tide between the coast and the breakwater. Trestle piers should only be of the length practically necessary. The ends of the trestles should not be embedded in stone mounds, as that encouraged sand and facilitated the formation **Lieut. Petit.**

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Lieut. Petit. of bars. The two piers could not be parallel for their whole length; they should be funnel-shaped, the greatest width at the mouth, gradually lessening to a certain limit within. The axis of the entrance channel should in direction be north-west and south-east, or even west-north-west for the western pier, if possible, so as to avoid an entrance perpendicular to the coast, which was always objectionable. This oblique direction facilitated the entry to the port. Vessels of a certain draught of water could only come in on the flood, and a rather long vessel when entering was subjected to a stronger tide on the starboard quarter than on the starboard bow already within their protection. This tended to swing it across the channel, especially if there was a strong west or north-west wind. This danger could be notably lessened by giving a north-west, or west-north-west direction to the channel. The ship, whether a steamer or a sailing vessel, could then come in with the wind astern, and cross the current obliquely. The western pier should be longer than the eastern, in order to slacken the strength of the flood, give shelter in bad weather, and permit outgoing vessels with light breezes to clear the eastern pier. With north-east winds they could also easily get out under sail. The only possible sea-works were those parallel with the coast, for they would not interfere with currents taking the same direction when at their greatest force. Such were, in his opinion, the essential conditions to be borne in mind in regard to the Belgian coast. Trestle elongations, spreading out from the existing piers, would only result in the formation of reservoirs of sand and silt, the removal of which would more than counterbalance the services the piers would offer to navigation.

Mr. Pettit Mr. PETTIT wished to remove some slight misapprehension under which the Author appeared to labour with respect to the jetties of the Adour. In the first place, the existing iron cylinders did not date from 1859, but from 1867. They replaced an open trestle structure put up at the earlier date, but which had soon been destroyed by the teredo. It had been hoped to apply the principle of placing movable panels between the cylinders, so as to have at will either open or closed jetties. But these panels, cumbrous and difficult to manage, had never been put in place, and up to the present time they had had to content themselves with skeleton structures. It should be stated that the cylinders were connected at the bottom by continuous rubble mounds, rising to within 6½ feet of low water.

In the second place, although it was undoubtedly true that the tidal oscillation was greater in the open sea beyond the bar than

Mr. Pettit.

in the river,[1] this could not be attributed to the jetties. Their distance apart, 170 metres (say 560 feet), which depended on some works executed in 1743, appeared to be sufficient; and, indeed, there might be noted on the plan he had furnished to the Author, a bank of sand advancing through the open work of the northern jetty, opposite the signal-tower, to a distance of 230 to 260 feet. This was just where the width of the mouth was least, being often reduced to 90 or 100 metres, and it was this bank which dammed the water of the river at low tide, and conversely arrested the free flow of the tidal water on the flood. If the distance between the jetties was greater the result would be the same.

He was in accord with the Author in the view that the effect of the works on the depth of the channel had been but moderate. Solid jetties appeared to have a prejudicial influence in arresting the sand and advancing the foreshore, and the bar. In his opinion the only certain benefit had been the regulation of the channel at the mouth. Before the construction of the works the Adour shifted about on the coast; from 1500 to 1578 its outfall was 36 kilometres to the north of the present channel; towards 1730, 2 kilometres to the south. At present the channel was fixed by the jetties, and could only vary within the limits of the 170 metres separating them. It was expected that by lengthening the cylinder jetties by 150 metres, so as to reach the highest point of the bar, matters would be mended; but though he himself hoped for this result, he was not sanguine. The extension had, however, been gazetted of public utility, and the works would be begun in the approaching summer.

To deepen the channel of the Adour flood water was required, for, contrary to the theory of Mr. Caland (referring possibly more to the interior of rivers than to bars), it was found that heavy floods had most effect on the bar. After such a downflow of fresh water they sometimes had 3 and even 4 metres in the channel at low water, and the sand-bank on the northern side was reduced, or disappeared altogether. On the other hand, the occurrence of ocean storms, with low tides, would reduce the depth to from 2 to $1\frac{1}{2}$ metres, or even to $1 \cdot 2$ metre (4 feet). The bar had even been known to emerge above low water, thus entirely closing the space between the jetties. In that case the water escaped through the spaces between the columns. Generally, however, after two or three days of fine weather the channel opened afresh.

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[1] At spring tides the rise and fall outside the jetties was 4 metres; in the Adour it varied from $2\frac{1}{2}$ to 3 metres.

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Mr. PLOCQ, Inspector-General of the Ponts et Chaussées (formerly Engineer-in-Chief of the harbours of Dunkirk and Gravelines, and subsequently of Boulogne and Calais), and Mr. GUILLAIN, Engineer-in-Chief of the harbours of Boulogne and Calais (formerly engineer of Dunkirk harbour), considered it specially necessary to indicate certain local conditions which appeared to them essential for the thorough comprehension of the different efficiency of the same methods of improvement adopted in various harbours on sandy coasts. With respect to Boulogne harbour, the chart of the French coast near the Straits of Dover showed that the shore, which was sandy between the estuaries of the little rivers Somme, Authie and Canche, changed to a high cliff north of the Canche, consisting of alternate layers of clay and rock. The cliff ran north and south up to Cape Alpreck, about 2 miles south of Boulogne; then it turned eastwards in a curve concave towards the sea, and approached the meridian of Alpreck again near Cape Grisnez. The size of this curve was 1 mile, and its chord 10 miles long. About $1\frac{1}{2}$ mile to 2 miles from the line of the cliffs there existed a sandbank, more than 12 miles long, pointing approximately N. $\frac{1}{4}$ N.E. The top of this bank, called the Bassure de Baas, was on the average $26\frac{1}{4}$ to $29\frac{1}{2}$ feet below low-water; whilst the adjacent depths, out at sea and between the Bassure and the coast, averaged from 59 to 66 feet. The flood and ebb tidal currents, alternately flowing nearly from south to north, and from north to south, had sufficient strength between the Bassure de Baas and the shore to prevent any deposit of sand over a width of about $1\frac{1}{2}$ mile, measured from the inner foot of the Bassure. Over all this expanse the clayey or rocky bed was laid bare, only shingle or coarse gravel being able to rest in the hollows of the bottom. This strip of hard bottom, kept constantly scoured, extended as far as the rocks at the foot of the cliff to the right of Cape Alpreck, and of the portion of the cliff which continued about 2 miles south of this cape: in this region, in fact, the principal currents between the Bassure and the shore were concentrated within a width of only $1\frac{1}{2}$ mile. In consequence, however, of the expansion of the current produced by the concavity of the coast to the north of Cape Alpreck, the velocity of the current diminished near the shore in front of Boulogne, and beaches of sand existed at the foot of the cliffs on each side of the harbour jetties. The sand, however, only formed a thin layer, over the bed of clay or rock, which diminished in thickness as it approached depths of from 20 to 23 feet below low water, and disappeared when depths of 23 to 26 feet were reached. The plan (Plate 2, Fig. 2), showed that the outer breakwater of the new

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harbour would be similarly situated, in respect to the removal of the sand by the tidal currents, as the rocks at the foot of Cape Alpreck; and it was difficult to see how sand could remain there. It was probable that the triangular recess between the south-west breakwater and Cape Alpreck would silt up. It might, however, be hoped that this accumulation of sand would not affect the depth at the foot of the outer breakwater; first, on account of the erosive action of the currents, which would arrest the advance of the sand before it attained the meridian of Alpreck or the angle of the breakwater; secondly, on account of the action of the waves which, breaking in this angle during storms with great violence, would take out to sea a large part of the sand which had been deposited in calm weather. The deposits also of sand inside the harbour, when completed, did not appear likely to exceed the practical limits of regular maintenance by ordinary dredging, considering that it had been proved that the quantity of sand held in suspension by the sea in all states of weather in front of Boulogne was not very large. Accordingly the site of the new harbour was characterised by specially favourable circumstances; first, very strong alternating flood and ebb tide currents, which had already laid bare the clay and rock at the bottom of the sea in front of the side of the breakwaters; secondly, on the south side, whence the flood-tide came, a length of nearly 2 miles of rocky cliffs, whose base was scoured by the currents, and which separated Boulogne from the great sandy beaches of Picardy; thirdly, the possibility of constructing the harbour in a bend of the coast, without any marked projection from the line of these cliffs, and consequently without risk of altering the flow of the currents between the coast and the Bassure de Baas. Under these circumstances the new harbour of Boulogne presented no similarity to sandy harbours, such as those on the south coast of the North Sea; and serious failures might occur if, in the event of the success of the Boulogne works, it was attempted to apply the same system for forming roadsteads in front of the harbours on the south coast of the North Sea. The jetty channel of Boulogne, situated in the centre of the sandy bay, was in reality a sandy harbour, but it differed from those on the North Sea coast, owing to the much greater agitation of the sea at Boulogne. Artificial sluices had been used, since the silting up of the Liane estuary, for maintaining a channel across the sandy beach which extended out in front of the Boulogne jetties, but they were always too feeble; this, however, would not be so if the Liane estuary could be restored to its original capacity. Since October 1881, dredgings of sand had been commenced outside the jetties, in order

Messrs. Plocq and Guillain. to maintain a channel with a depth of 5 feet below the lowest tides, which was the depth requisite for enabling the Folkestone and Boulogne steamers, drawing $8\frac{1}{2}$ feet of water, to enter at fixed times. These dredgings were performed by sand-pumps, as at Calais and at Dunkirk, which could continue working in waves from 2 to 3 feet high. During two hundred and twenty-seven days, from the 15th of October 1881, to the end of May 1882, the dredging could be carried on, outside the jetties, for six hundred and eighty-one hours, spread over ninety-two days; thus bad weather and repairs stopped the work for three-fifths of the whole period. At Calais, where the sea was less rough, the coefficient of interruption was only one-half, and at Dunkirk only $\frac{1}{2 \cdot 25}$. The dredgings at Boulogne were conducted by a contractor, with his own plant, at a price of 11·3*d.* per cubic yard dredged and conveyed 1 mile out to sea. From the experience of the first seven months, the cost price was 9·3*d.* per cubic yard, including solely labour, fuel, repairs, and maintenance. The cost would diminish in the future, as occurred at Dunkirk, in proportion as the depth increased, enabling the work to be carried on during low tide. Hitherto 82,500 cubic yards had been dredged, and already an increase in depth had been observed.

With respect to the harbours on the southern coast of the North Sea, all the French ports of the North Sea opened on to nearly flat and very extensive beaches of sand. As the flood-tide coming from the west was the strongest, and the south-west to west winds were the most frequent, the direct action of the wind on the dried sands of the beach, and the combined action of the currents and wind, caused a definite travel of sand towards the east along the coast, though this motion was arrested during the prevalence of east winds. Every solid jetty, connected with the shore and forming a transverse groyne, was necessarily sooner or later overtopped near the land, and outflanked at its outer end, by the sand travelling along the coast. The effect of storms was to raise the level of the bottom where the waves broke, as observed at Calais and at Dunkirk. After each violent storm the low-water mark tended to advance in the harbour channel at the outlet of the jetties, towards the west with westerly storms, and to the east with easterly storms, without generally affecting the outer channel further out; the inroad of sand being thus nearly always confined to within 200 or 300 yards from the head of the jetties. The storms, moreover, brought a large quantity of sand (sometimes 25,000 to 40,000 cubic yards in a few days), through the open timberwork jetties into the inner

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channel at the foot of the windward jetty. This sand was mostly blown in by the wind from the dry beach at low water, and some also was brought in by the waves which, having passed through the jetty at high tide, deposited in the comparatively calm channel a large portion of the sand held in suspension. Another circumstance, common to these ports and peculiar to them, gave rise to arrangements which would not be equally applicable elsewhere, namely the function which these ports discharged in draining the country, whose general level was below high water. The drainage waters had to be provided at these ports with outlets and sluices, which, retaining them at high tide, ensured their discharge between half-ebb and half-flood tide.

There was a certain difference in the nature of the drainage waters discharging at the ports of Calais and Dunkirk. At Dunkirk the waters were much more muddy than at Calais. Carried towards the west along the shore (owing to the line of outer banks which formed the Dunkirk roadstead) by the ebb tide, at which period the discharge always took place, the waters deposited a portion of their mud on the strand during the flood tide, when the current turned towards the south before resuming an easterly course. In consequence the upper portions of the beach were silty, and the lower and submerged portions, both to the west and in front of the port, were composed of sand mixed with silt; whilst to the east the sand was nearly pure. Moreover, the water in the channel between the jetties at Dunkirk contained a large amount of mud at the time of the filling of the harbour, which, forced back by the tide, was deposited in the interior. At Calais, on the contrary, the drainage waters were carried further out at sea (owing to there being no roadstead parallel to the shore); the interior of the harbour silted up but little, and the sands in front of the harbour, as well as on the east and west strands, were almost pure. Besides, it must be observed that, in front of Dunkirk, the five lines of sandbanks which stretched parallel to the coast broke the sea outside and maintained a comparative calm, even during heavy storms, in the deep water which formed the Dunkirk roads between the first line of these banks and the shore; whereas Calais, having only the low and narrow bank "du Riden" in front of it, was exposed to storms from the open sea, though much less violent than in the region south of Grisnez. Lastly Calais, being situated very near the Straits, had very strong currents passing by the ends of its jetties; whereas the currents were much weaker in the Dunkirk roads. These different conditions explained—first, the different configuration of the strands on each side of these two

Messrs. Plocq and Guillain. ports; secondly, the different efficiency of the same methods employed for maintaining the depths at these ports. At Calais the sand of the west beach, not being rendered coherent by silt, was easily carried eastwards by the winds and currents, and was readily put in suspension by the waves, so that sand accumulated as much on the east side of the port as on the west; moreover, the shelter afforded to the east by the jetties from the prevalent westerly storms favoured the deposit of sand on that side. The results were—first, that the low-water mark on each side of the port followed a straight line, nearly perpendicular to the line of the jetties, which inclined towards the west at an angle of 67° to the coast line; secondly, that the eastern beach was even larger than the western; thirdly, that easterly winds tended to fill up the entrance with sand quite as much as westerly winds. At Dunkirk the silty western beach retained a portion of the sand travelling from the west, and tended to advance; whereas, on the contrary, the eastern beach was concave for some little distance from the eastern jetty, and the low-water mark approached and remained nearer the land. The results were—first, that the low-water line on the west side, near the port, continued for some distance parallel to the line of the west jetty, which, however, made a larger angle with the general line of coast than at Calais (79° instead of 67°), whereas the low-water line to the east diverged at once from the line of the jetty channel; secondly, that the westerly storms were the most prejudicial in silting up the entrance, whereas the easterly storms, by turning back the sand of the western beach, did more good than harm.

In front of both harbours the bed of the sea, below low water, descended with a gentle inclination to a depth of 10 to 13 feet, then with a more rapid slope to the great depths of 50 to 65 feet. Owing, however, to the difference in the strength of the tidal currents and in the force of the waves, the slope of the great depths was only 1,150 to 1,300 feet from the end of the Calais jetties, whereas it was from 2,000 to 2,300 feet away from the Dunkirk jetties. It was shown in the Paper that very nearly the same methods had been adopted at the two harbours for obtaining a suitable depth at the entrance and inside.

The prolongation of the jetties should follow the natural progression of the strands, but should not outstrip it, for not only did hasty extensions produce no permanent improvement in depth, but they, moreover, hastened the increase in the depth of sand from whence the winds and waves took the materials which they deposited between and in front of the jetties.

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The formation of these harbours was due to sluicing, which had been gradually developed as a means of deepening, all the less costly because the works had been, and always were, in a great measure necessary for the drainage of the district.

At Calais, with an average discharge of 450 cubic yards per second, lasting with efficiency from one-half to three-quarters of an hour, the sluices had procured—first, in the channel between the jetties, a depth of 5 feet 9 inches to 8 feet 2 inches below the zero of the charts (zero being the lowest tides known); secondly, outside the jetties, for a width of 130 feet, a minimum depth which varied, according to the frequency of the storms, from 10 inches to 4 feet below zero, the direction of the external channel being slightly inclined to the east of the line of the jetty channel. For improving the harbour still more, and for admitting the mail steamers of greatest draught at low tide, a new sluicing basin of 235 acres was projected in 1875, and commenced in 1880 on the upper part of the east beach. This basin would increase the discharge of the sluices from 450 cubic yards per second (as at present) to more than 1,100 cubic yards, the effective period of sluicing remaining the same.

At Dunkirk, with an average discharge of 510 cubic yards per second, having an efficient duration of about three-quarters of an hour, the sluices gave: (1) in the inner channel, the same depth as at Calais below zero; (2) outside the jetties, over a width of 100 feet, a minimum depth varying from the zero to 2½ feet below, according to the weather. When the working of the sluices was stopped for some time for repairs the entrance channel gradually shoaled, the bottom having risen to 2½ feet above zero. For a long time the external channel of Dunkirk harbour was almost always deflected to the east, at an angle of 20° to 30° to the prolongation of the line of the jetty channel. This deviation was due to the tendency of the west beach to encroach on the channel. It was in order to bring back the external channel to the line of the inner channel that Mr. Plocq employed, from 1865 to 1877, the system of movable jetty mentioned by the Author. This floating movable jetty, formed of thirty guide frames, each 33 feet long, fastened end to end, was stranded in prolongation of the east jetty in very fine weather, and the sluicing current, thus guided, scoured out a channel in the line of the jetty channel; and this improvement in direction usually lasted till the next severe westerly storm occurred. Ten of these operations in the year sufficed to maintain the entrance channel in a fairly good direction. Thanks to these means, the Port of Dunkirk had usually a depth

Messrs. Plocq and Guillain. at high water, in the entrance channel, of 20 to 21½ feet during ordinary spring tides, and 16½ to 18 feet at neaps. This depth being inadequate, Mr. Plocq proposed in 1861, and adopted in 1865–70, a new series of sluicing basins, which would raise the average discharge of the sluices to 1,070 cubic yards per second. This arrangement was to accomplish three objects of equal importance: (1) the military defence of the place; (2) the improved drainage of 111,200 acres of low lands, discharging their waters at low tide through Dunkirk; (3) an increase in the sluicing power. This was following out Vauban's principles, who, in the seventeenth century, had organised in this way the ports and fortified places of French Flanders. As the drainage waters had only an intermittent flow into the sea at low tide, it was a great advantage to provide great reservoirs near the sea, into which they could flow and be stored up whilst the high tide prevented their flowing into the sea. For this purpose it was only necessary to connect the upper ends of the sluicing basins with the drainage canals, closing the communication by protecting sluices provided with sea gates. In this way the sluicing basins would act as reservoirs for land floods, and the scouring sluices for the discharge of the fresh waters; and then, when it was not necessary to let out the fresh waters at once, the gates of the protecting sluice had only to be closed to allow the basins to be filled at high tide with salt water, which could be used for scouring the channel at low tide. The ditches of the new fortifications (rendered necessary by the extension of the port) had been made 165 to 230 feet wide, so as to serve both as reservoirs for the fresh waters and sluicing basins of salt water, whilst being improved as defensive works; and thus an improved means of drainage, and new sluicing basins, had been obtained at a cost which would have been reasonable for either object, and a large portion of which was necessary for defence. The two new scouring sluices, having a total width of opening of 100 feet, at the outlets of the east and west trenches respectively, for emptying reservoirs having an area of 163 acres, were completed, and had served for some time to discharge the fresh waters, but the reservoirs were not quite finished.

The new sluicing basins at Calais and Dunkirk would in all probability increase the depth of the channel between the jetties to 13 or 16½ feet. The scouring current, whose efficiency rapidly decreased on leaving the jetty channel, also readily removed the sand, brought in by storms, from the channel for 300 to 600 feet beyond the jetties; but there would remain, between the deep

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inner channel and deep water outside, a more or less elevated plateau which sluicing could not lower. It was probable that the increased sluicing power would not procure a depth of more than $6\frac{1}{2}$ to $8\frac{1}{4}$ feet below zero over this plateau either at Dunkirk or at Calais. But in order that a vessel drawing 23 feet of water might enter Dunkirk harbour at high water neap tides, with at least 20 inches of water under its keel even in rough weather, it would be necessary for the inner channel to be at least 10 feet below zero, and the outer channel $11\frac{1}{2}$ feet below. Vessels of that size could enter Calais in all weathers at high water without any improvement being needed, as the range of tide was more than $3\frac{1}{4}$ feet greater at Calais than at Dunkirk. Calais, however, was a mail-packet harbour, and as it would be desirable that mail-boats drawing $14\frac{3}{4}$ feet should be able to enter at low water neap tides, the inner channel should be 13 feet, and the outer channel $14\frac{3}{4}$ to $16\frac{1}{2}$ feet below zero. Though the sluicing basins in course of construction would probably procure the desired depth in the inner channel, and near the head of the jetties, at both ports, they would certainly not give a sufficient depth in the outer channel. The Government accordingly decided, in 1875, by the advice of Mr. Plocq, to assist the deepening of the outer channel at Dunkirk by dredging. As the result was satisfactory, the same engineer proposed, in 1881, and obtained permission, to dredge the outer channel at Calais. The success of the dredging operations at Dunkirk and at Calais was entirely due to the employment of sand-pumps, with flexible tubes, placed on screw steam hopper-barges, which conveyed the material to the place of deposit. These machines possessed the advantage of working easily in a moderate swell (from 1 foot to 2 and even 3 feet); of not being liable to damage from the swell; of being held in working by a single anchor, and therefore able to start work in a few minutes; and, lastly, of not impeding the entrance of the harbour with their moorings and with separate barges.

Between February 1876 and the 1st of May, 1882, 955,000 cubic yards of sand had been dredged beyond the Dunkirk jetties, of which amount about 490,500 cubic yards had been removed during the year ending the 1st of May, 1882. Although the new sluicing arrangements were not yet in operation, and the working even of the old sluicing basins had been considerably reduced by reason of the new dock works, which diminished their area, the smallest depth in the outer pass was 5 feet 9 inches below zero in May 1882, making an increase of $3\frac{1}{4}$ feet beyond the greatest depth obtained by the sluices alone. The greater portion of the raised plateau, from

Messrs. Plocq and Guillain. 1,600 to 2,000 feet wide, which formerly separated the deep inner channel from the roadstead, had been deepened to more than $8\frac{1}{4}$ feet below zero, and was therefore on the average more than $6\frac{1}{2}$ feet below its old level. Moreover, the pass had been now considerably extended on both sides, and it was being still further enlarged towards the west, to prevent the sudden encroachments of the west beach during storms from reaching the navigation channel. Work was commenced with one dredger, which was improved as experience dictated; the number had been from time to time increased, and since March 1882 four sand-pump hopper-dredgers had been at work, their total strength being 560 I.HP., and their hoppers having a total capacity of 1,023 cubic yards. These four dredgers removed 52,300 cubic yards of material, measured in the hoppers, in one month of average work, and conveyed it $2\frac{1}{2}$ miles out to sea. The work was done by contractors, who owned the plant. The contract price in 1875 was 21·1*d.* per cubic yard, dredged and conveyed away; but subsequently the price was reduced to 11·6*d.* in 1880, 10·2*d.* in 1881, and 8·7*d.* in 1882. The cost price, exclusive of insurance, depreciation, interest on plant, and profit, had been regularly decreasing, owing to successive improvements in construction and working, and also because the increased depth already obtained had now admitted of almost continuous working, whereas at the commencement the work could only be carried on during the higher half of the tide. This cost price, including wages, fuel, maintenance, and repairs, had exceeded 7·3*d.* per cubic yard up to 1880; since then it had regularly diminished, and appeared now to amount to about 2·9*d.*

The dredging at Calais were only commenced on the 20th of June, 1881. Already in less than a year, an improvement had been effected nearly as great as at Dunkirk, with much less plant and less expense. Profiting by the experience gained at Dunkirk, dredging was commenced at Calais with three sand-pump dredgers, one a hopper-dredger and two not, and now the work was being continued with a single sand-pump hopper-dredger. The three dredgers had removed 180,500 cubic yards of material in the five months ending November 1881. The hopper-dredger, which had been working alone since December 1881, a screw-steamer of 120 I.HP., holding 220 cubic yards of sand, and furnished with a rotatory pump capable of discharging 1,300 cubic yards of water per hour, had removed 107,200 cubic yards in the six months ending May 1882; making a total amount of 287,700 cubic yards in eleven months (Fig. 2). Now the outer channel, at the end of

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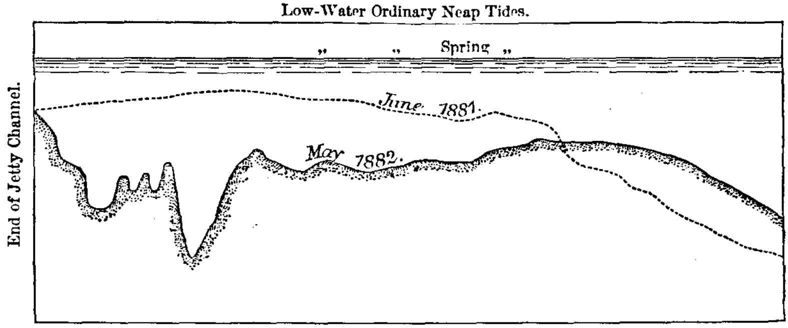
May 1882, had a minimum depth of 6¼ feet below zero, which was more by 2 feet than the greatest depth ever previously attained, for a brief period, by the sluices alone. The plateau also, which formerly extended between the inner channel and the roadstead, had been lowered, on the average, to more than 7¼ feet below zero, or more than 5 feet below its original level. The price to be paid for the future to the contractor, as arranged in February 1882, was 6·55*d.* per cubic yard, measured in the hopper, dredged and conveyed 1 mile out to sea with his own plant. The expenditure on wages, fuel, maintenance, and repairs, in dredging 66,831 cubic yards, during the first four months of 1882, amounted to £844 13*s.*, giving a cost price of 3·03*d.* per cubic yard.[1] The dredging at Calais had produced a more rapid improvement than at Dunkirk, for the following reasons: first, the sand, being purer, was drawn up with the water by the pumps more readily, and in larger quan-

Fig. 2.



25 feet below zero of charts.

Scales :—Vertical $\frac{1}{250}$; horizontal $\frac{1}{5000}$.

Calais Harbour.

Section in centre line of channel beyond jetties, showing results of dredging.

tities; secondly, the deep sea slopes were nearer the ends of the jetties; thirdly, the plant had been perfected by the experiments which had occupied time at Dunkirk. These advantages far more than compensated for the greater exposure at Calais.

[1] The contractor had therefore a balance of 3·52*d.* for insurance, deterioration, interest on plant, and profit. If 0·73*d.* was allotted for profit, there remained 2·79*d.* for the other items on 200,000 cubic yards in the year, equivalent to about 30 per cent. of the original value (£8,000) of the plant.

Messrs. Plocq and Guillain.

The following Table furnished a comparison of the dredging operations at the two harbours for a period of nine months, ending the 31st of March, 1882. This comparison could be very easily made, as the sand-pump hopper-barge at Calais and one of those at Dunkirk were identical; they belonged to the same contractor, and were worked by equally experienced gangs.

Port.	Total amount dredged and removed in 9 months = 274 days by one dredger of 120 I.HP.	Number of regular working days.	Number of working hours.			Average product per hour of dredging.	Number of idle days.		Number of days during which the height of the swell was—		
			Dredging.	Conveyance, discharging, and stoppages at the site of the works.	Total.		Owing to bad weather.	For repairs.	0 to 1 foot.	1 foot to 2 feet.	Over 2 feet.
	Cubic yds.					Cub.yds.					
Dunkirk	79,205	151	1,410	498	1,908	56	80	6	116	119	49
Calais .	154,479	135	919	458	1,377	169	85	19	92	89	93

The influence of the greater purity of the sand at Calais was shown by the amount dredged in one hour being three times greater at Calais than at Dunkirk, with similar dredgers; the greater agitation, however, of the sea at Calais reduced this advantage, so that, in the end, the annual amount of work with the same dredger was only double at Calais what it was at Dunkirk. But as the length to be dredged at Calais beyond the jetties was only one-half that at Dunkirk, the same improvement might be effected at Calais with one-fourth the dredging plant, were it not probable that the greater mobility of the sand would necessitate a greater widening of the outer channel than at Dunkirk, both to the east and west, so as to provide receptacles beyond the regular channel for the deposits brought in by easterly and westerly storms.

When once the requisite depth was obtained at either harbour, some years' experience would still be needed to ascertain the average annual amount of deposit. For a long time a large part of the sand dredged would be due to the falling in of sand in the gradual formation of a gentle slope between the neighbouring banks and the bed of the channel, as well as to the aforesaid deposit. However, as the present work consisted in forming hollows near together, deeper than the required level, which filled up by the falling in of the adjacent sands, as well as by the deposits due to the winds, currents, and waves, a greater amount of silting up had to be contended with now than when the new state of equilibrium should have been attained; and it was therefore certain that the existing means of deepening would suffice for the future maintenance of the pass. The dredging of 196,000 cubic yards annually, costing under £6,000, would therefore suffice to maintain the pass at Calais. It seemed probable that the maintenance of the outer pass at Dunkirk would not cost more; it might even be less when the large accumulations of silty sand, in front and to the west of the harbour, were to a great extent removed by the great dredging operations for forming the channel. Messrs. Plocq and Guillain.

Though improvements effected by dredging would have to be maintained by dredging, they did not consider that sluicing could be dispensed with for maintaining the depth of these harbours. Although a small part of the sand and silt removed by the sluicing current might be deposited on the western beach, whence it would be brought back afterwards, owing to the course of the currents at Calais and at Dunkirk, it was certain that the greater portion would be carried out to sea and not return. The sluices, accordingly, ensured the scouring out of the inner channel and the portion of the outer channel near the ends of the jetties, an important gain accomplished at a small annual expense for working and maintenance.

To sum up, they considered that there were no absolute rules for these matters. The local conditions should be studied in each case, and if they admitted of powerful sluicing arrangements being cheaply constructed, this natural power should not be neglected. Very powerful sluices, suitably arranged, could maintain a depth of 13 feet below low water, between and for a short distance beyond the jetties, in sand of a favourable nature. Sluices alone would probably never lower the rest of the outer pass more than $6\frac{1}{2}$ to $8\frac{1}{4}$ feet below the lowest tides. If this depth, added to the rise of tide, was insufficient, or if a great depth at low water was needed, for mail packets for instance, sand-pump hopper-dredgers, together with the most powerful sluices available, would certainly effect the desired result, at a cost which would vary according to the conditions of the sea and the purity of the sand; but which, from the experience at Dunkirk, Calais, and Boulogne, would not generally be excessive. The employment of dredgers for maintaining the jetty channel would necessitate a fairly large width, which it was not always possible or convenient to provide.

In every instance it was important to present as few obstacles as possible to the natural forces along the coast, not to raise solid jetties above the beach, and not to prolong the jetties, except when

Messrs. Plocq and Guillain. obliged by the progression of the foreshore. Solid jetties caused a progression of the dunes, and, consequently, of the whole beach; the extension of open jetties caused an advance of the low-water line, and thus increased the silting-up tendency of the beach.

The works of the Tyne and the Clyde were striking examples of remarkable practical successes attained by natural scour and dredging. They reasonably prompted the combination of artificial sluicing with dredging, as far as possible, where the tidal capacity of estuaries had been unfortunately compromised, and especially where these estuaries, converted into large rich tracts of land, could only flourish in rainy seasons by efficient drainage through the harbours.

Lastly, it should not be forgotten that the works at Boulogne were not strictly improvement works of the harbour, but consisted in the creation of a roadstead extending nearly $1\frac{1}{4}$ mile out to sea in front of the harbour, and that this project was in no way comparable with the improvement of the entrances to the harbours at Dunkirk and at Calais, and of the actual harbour of Boulogne. This artificial roadstead would give Boulogne what Nature had given to Dunkirk, and in a few years would render the deepening and maintenance of Boulogne harbour more easy.

Baron de Rochemont. Baron QUINETTE DE ROCHEMONT was of opinion that the embankment of the lower Seine had considerably improved the navigation between Rouen and the sea; at the same time the channel below the embankments left much to be desired on account of its want of depth and of its shifting nature. The Rouen authorities had on several occasions demanded the extension of the embankments, but owing to the trouble they had occasioned in the regimen of the bay, and the fears entertained for the future of the Port of Havre, it had not been possible to go farther in that direction.

The ebb and flow caused very rapid currents both in the bay and in the river. The ascending currents passing over the shoals in the estuary got charged with sand, which was deposited at a point more or less near its origin; the descending currents acted to reconvey this material to its first position. But the ebb could not take back all the material brought in by the flood, consequently, little by little, silting occurred. Previous to the construction of the embankments an approximate equilibrium was established, and the depth of the annual deposit was relatively small. But this condition was altered by the embankments; the action of the ebb had been modified, it had become less than formerly, while the flood remained the same. The flowing current caused by the rise of the tide was virtually a factor of the tidal wave entering

Baron de Rochemont.

the channel. Its impetus was generated and developed in the open sea; and its action on the bed of the lower part of the outfall remained the same, whatever the reduction in capacity of the upper part, if the depth remained constant.

The section at the inlet had not varied; there the layers of water were of equal depth. The shoals inside the bay near the outfall were covered with water of less depth, at the time when the impulse of the tidal wave was still strong. Consequently they were easily eroded, and the flood tide carried silt as formerly. Towards the upper limit of the tide the speed of the current was progressively diminished to nil, when silting occurred with great ease. The water which formerly came up freely was now obstructed by the shoals, and could only act towards the east through the embanked channel; for the whole perimeter above the bay the water was without sensible velocity. Hence the deposit of matter in suspension lasted during the whole period of slack water at Havre, being not less than one hour and a half.

Formerly the ebb caused a tidal current over the shoals below the level of the water, which assumed a considerable slope between Quillebœuf and Havre. The average velocity increased and favoured the removal of part of the surface of the banks. This action made itself felt over the whole extent of the shoals; the fluid currents thus took up much of the deposit, which it reconveyed to the sea. This action continued very efficaciously till low water. At present the retreat of the water over the whole bay occurred without velocity. The point of departure, except for the embanked channel, had receded to the meridian of Hode. Not until much lower down was the velocity sufficiently accelerated to produce unsilting. The deposits situated above, no longer scraped off by the ebb, were gradually rising, and became uncovered at a much earlier period than formerly. True, the tide-level having been lowered in the Seine, a larger quantity of the water passed off by the channel, when the embankments were uncovered, but that produced no useful effect in carrying away silt.

The embankment of the Seine, by disturbing the former equilibrium, had therefore resulted in promoting the rapid shoaling of the bay. The growth of the deposit was progressively quicker as the alluvial matter found its depositing ground restricted by the daily diminution of the area of the bay, whose capacity was already decreased by one-half. This reduction of capacity of the bay had a further effect in modifying the regimen of the currents and tides. The secondary tide produced in the northern part of the mouth at the termination of the flood-tide, and when

Baron de Rochemont.

the bay was full, had increased in a notable manner. It was normal to the jetties of the Port of Havre, and its maximum intensity coincided with the hour of high water. Its velocity had reached as much as 1·8 to 2·5 knots for tides of coefficient 100. This increase added to the difficulty of making the port. On the other hand, the time of high water was thirty-eight minutes later at springs, and seven to eight minutes later at neaps. At Honfleur the advance was nearly constant, twenty-six minutes. Mr. Vauthier was mistaken in maintaining that a new state of equilibrium had been established. On the contrary, the shoaling continued at a considerable rate. In January 1881 the zero curves (contour line of lowest known tide adopted by the Admiralty charts) passed through the meridian of 2° 12′ west of Paris, exactly where the 11-metre curve was situated in 1875. This deposit of 11 metres in six years deserved to be noticed, but Mr. Vauthier passed over it in silence. Little by little the shoaling was increasing at the outfall and approaching Havre. The entrance to the port, towards the south-west, was preceded by an almost level plateau, about a mile across, on which, at lowest neap tides, there was only a depth of 7·9 metres (26 feet). The least decrease in this depth would suffice to compromise the port.

Several mishaps having occurred to vessels ascending the Seine, while they were yet in the bay below the embankments, Mr. de Freycinet, when Minister of Public Works in 1879, appointed a commission to inquire into the improvements that appeared necessary in the regimen of the bay. That commission was composed of eminently competent persons: four Inspectors-General of the Ponts et Chaussées and Mines, two hydrographic engineers, a captain of the navy, and three delegates from the Chambers of Commerce of Havre, Rouen, and Honfleur. After an exhaustive study of the questions submitted, the commission concluded that it was necessary to abandon all prolongation of the embankments, and pay close attention to the movement of the shoals. It was not disputed that the lengthening of the banks would improve the entrance to the Seine, and that consequently it was for the interest of the river navigation. But at the same time the work could not be undertaken on account of the position of Havre at the mouth of the Seine, and of the disastrous consequences its execution would entail on the maritime interests of that port.

The improvement of the Seine outfall was therefore a particularly delicate matter. So far no solution had been found that would meet all the interests concerned. The hydrographers were engaged on a new survey of the bay to ascertain what had occurred since 1875, but the results of their observations were not yet made public. Mr. Vauthier had not brought forward any argument that was not already well known; it would therefore be perhaps prudent to await the report of the new survey to see if any new facts were brought to light which would result in the acquisition of a complete knowledge of the regimen of the bay. Baron de Rochemont.

Mr. G. ROYERS, engineer of the Port of Antwerp, remarked that the ports between Calais and Blankenberghe were, as the Author stated, kept up by jetties, nearly parallel, having an upper part of trestle work supported on a solid mound. The superstructure was to indicate the channel, to carry at the extremities signals, and to provide means for the warping of vessels. The solid part served to direct the sluicing current generally adopted, to prevent the ingress of sand, and to protect the piles of the trestle work from the force of the waves. It should be considered that this mode of construction was alone available on very flat sandy coasts. The line of the dunes or of high tide formed the limit of land and sea, and it was either just in front of or behind that line that the harbour must be made. If it were wished to establish a port beyond that limit it would be necessary, in order that it should be a port at all, *i.e.*, capable of affording shelter against storms, that space should be almost entirely closed in, capable of arresting the waves, and consequently the littoral currents. But if the free passage of these currents were interfered with there necessarily followed deposits, whose continuous action sooner or later effected the advance of the foreshore. The analogue of this was to be found in the convexity of a river curve when spurs were projected from the bank, and the result was all the more certain on a sea-coast, in that the tides on a shore worked two ways, and were of unlimited width. Experience showed that when it was desired to advance the coast, as for preserving embankments, or reclaiming land, no more effectual means could be adopted than of throwing out projections or obstructions. But if this were an excellent means of attaining a given end, it by no means followed that its efficiency was equal when the end was diametrically opposite. No doubt the advance of the shore might be made slower by the choice of a particular form for the obstruction, nevertheless it must be considered an axiom that the projection of a closed harbour from a sandy shore was, under all circumstances, very dangerous. Mr. Royers.

It was in view of this that the ports of the North Sea had been established on firm land, with open jetty approaches, which interfered as little as could be with the littoral currents, and it was hardly to be expected that good results could be achieved

Mr. Royers. with solid jetties. Some engineers maintained that it would suffice to give solid jetties a curved form in order to prevent the advance of the shore. It was thought that such structures, carried out to a great depth of water, would prevent the accumulation of sand except in the exterior angles formed by the jetty and the coast, and that even this deposit would cease as soon as it had reached the exterior line of the jetties, where there could be no silting owing to the velocity of the currents. This opinion was not well founded, and although under such conditions the silting might take a long time to reach the end of the jetties, it could not be allowed that their construction would have no influence in disturbing the primitive equilibrium of the banks and channels. Another difficulty of the North Sea coast was the silty deposit formed by the water within spaces free from the agitation of the waves. These two circumstances had led, and would lead, to the establishment of ports within the coast-line connected with the sea by open jetties, affording a passage of limited extent opening into as many floating basins as possible. To maintain such channels no better system than sluicing had yet been discovered, and it successfully performed its functions. But to extend its effect as far as the bar, closing the entry to the ports, was a more difficult matter. So far the results had been mediocre. Perhaps it was that sluicing had not been applied on a sufficiently large scale. Considerable scour was produced close to the sluicing-basins when the water was let out, but the effect decreased rapidly near the sea, when the water escaped on all sides and did not retain sufficient force to affect the bar, or probably it was diverted into a direction different from that of the channel. The remedy was not obvious, nevertheless it might be that if means were found, as at Dunkirk, of guiding the sluicing-water and at the same time of providing an immense quantity, so as to be able to introduce into the channel more water in a given time than it could pass off, doubtless a notable effect might be produced on the bar. Such assisted natural action was far preferable to dredging, which, though it controlled the navigation to a certain extent, always had the disadvantage of not being applicable at certain times, especially in bad weather, when, as a rule, it was most wanted. It was obvious also that the filling-up by nature of dredging channels would follow very rapidly, and even supposing that dredging could be resumed immediately after a storm, some time elapsed in restoring the *status quo*. Sluicing might, on the other hand, be considered as one of the constants whose combined effect produced the configuration of the shore.

Experiments had been made at Ostend in the direction of

Mr. Royers.

guiding the sluicing-water by laying lines of big bottles or of saucissons, the former filled with gunpowder and the latter with dynamite, discharged a little before the water was let in, so as to blast a channel and prevent the spreading of the water over too large an area. So far these trials had not been successful, but they were interesting enough to deserve record.

It did not appear that there was any other mode of improving such ports as were in question, except by constructing breakwaters parallel to the sandbanks and consequently to the littoral currents. By this means the currents were not diverted, and the existing deep-water passes could be maintained, with the result that vessels could be sheltered from wind and wave at the same time that their anchorage was easily accessible. Ships would await the time of high water to enter the harbour basins, as was the practice in river ports, such as Liverpool, Hamburg, Bremerhafen, Rotterdam, Antwerp, &c. Such a system, assisted by copious sluicing, by dredging if necessary (securely protected by the breakwater), and other expedients such as blasting, jets of water under pressure, raking, and the like, would allow of a large development of the usefulness of harbours on the coast. It would even be possible from the moment the roadstead became safe to seek some means of raising vessels of heavy draught, as was done in floating docks, so as to pass them over the bar. It might be useful to search for some spot where the coast sloped rapidly, and where the depth was considerable, so as to apply some system allowing the vessels to reach the quays at all times of the tide.

The Port of Ymuiden was established on principles contrary to the foregoing, but Sir John Hawkshaw had told Messrs. Stœcklin and Laroche that he was only deterred from adopting the parallel jetty system by dread of the expense, and this opinion appeared to have been shared by Mr. Dircks, the Dutch engineer, who directed the works.[1] The converging jetties at Ymuiden had caused a certain advance of the foreshore, but their principal result had been a considerable silting-up inside. It had even been decided completely to abandon the effort to maintain the depth over the whole extent enclosed by the jetties, and it cost a great deal to keep up a channel only so wide as was necessary. It was not safe yet to pronounce judgment on the Ymuiden works, but it had certainly not been proved that they constituted any advance on the parallel jetty system with judicious sluicing, making allowance

[1] See note, p. 103, *post*.

Mr. Royers. for the improvements which the latter was susceptible of, and of which the greatest was the establishment of detached roadsteads.

The foregoing considerations were equally applicable to the estuaries of rivers. As the Author stated, the outfalls of rivers through alluvial plains were principally maintained by the action of the tide. Such rivers should be capable of receiving the greatest possible volume of tidal water, and all artificial works tending to diminish it should be looked upon as dangerous. There was no doubt that the bed of a river might be improved by longitudinal embankments, but if those works in any way interfered with the volume of the waters scouring the estuary, their total effect would assuredly be prejudicial. To execute such works was akin to straightening and enlarging the corridor of one's house while at the same time narrowing the entrance, and they must assuredly bring about such results as the Author had indicated at the bottom of page 29, and would necessitate the prolongation of the jetty seaward. Prolongations of that sort were about the most dangerous things on the North Sea coasts, and without referring to the Hoek of Holland for confirmation, it might be acknowledged that their immediate effect would be to recede the lines of deep water further and further, and to create a bar more and more difficult to get over.

In these matters there was no absolute rule, but all those who attentively studied the conditions of rivers with outfalls into sandy estuaries of small depth of water would acknowledge that the least interference with the free scope of the tide would be eminently injurious. The principle to be followed in carrying out improvements in such cases was therefore to take great care that no river works should be allowed to lessen the impulse of the tidal wave; and if it were obligatory to encroach in particular localities, artificial excavations should be made in others to restore the equilibrium. Further, if such excavations tended to silt up they should be dredged. By this means works would only be carried out at places of acknowledged accessibility, while the other system led to the establishment of undertakings at inaccessible points, that was in the open sea, under immense difficulties, and whereof the results could never be ascertained with certainty.

Mr. Rymer-Jones. Mr. T. M. Rymer-Jones thought that the difficulties to be overcome or avoided in making a harbour at Madras arose from the strong sand-charged current which flowed periodically from north to south and south to north, according to the prevalence of the different monsoons. A breakwater, or system of breakwaters, if of a close form and commenced from the shore, would, in the first place, stop this natural current and cause an immediate deposit of the sand with which, close in-shore, it was heavily charged, thereby causing the rapid silting up of the shore ends of the breakwaters; secondly, the obstruction of the current for the whole length of the breakwaters seaward would create a race past their extremities which would cause a heavy scour, and also materially interfere with the steering of a vessel making the harbour. To avoid these difficulties (and aware that an open-piled pier of 1,000 feet in length, situated near the custom-house, had stood for several years without any accumulation of silt at all), he proposed to the Harbour Commission of 1868, at Madras, to utilise this pier with another and similar pier, to be built opposite the Madras lighthouse, situated 1,200 yards more to the south, so as to pass through the alongshore sand-bearing current without obstructing it, and afterwards to continue the breakwaters in stone sufficiently far seaward to give an anchorage of 265 acres, leaving two openings of 600 feet each, bearing N.E. and S.E. from the centre of the harbour, for ingress and egress of shipping with any wind. The advantage of passing rapidly through the almost continual surf on the Madras beach, before commencing the stonework, would be a great gain in itself. There were several other special points taken into consideration, which it was unnecessary to refer to. The vital principle in the design was the non-interference with the sand-bearing current and the avoidance of an expensive and useless struggle. The cost of the entire works, omitting the pier already completed, was estimated at £600,000. The alteration might be made even now if required. Mr. Rymer-Jones.

Mr. L. L. Vauthier generally agreed with the opinions on estuaries put forward by the Author. He was also in accord with him, that if it were advantageous to regulate an estuary very irregular in width, a too great reduction of the estuary channel would infallibly injure the outlet. But it should be borne in mind that it was impossible to consider an estuary apart from the river of which it formed the termination, or to leave out of account the oscillations of the sea into which it opened. Virtually, the essential factors which should govern the dimensions to be given to the mouth of a tidal river were the quantity of sea-water it received at every tide, and the volume of fresh water of which it was the conductor. It was incontestable that the larger the estuary the more sea-water it took and gave back. But it was not this water which contributed most advantageously to maintain the depths at its mouth. The water which was most efficacious in this respect was that, dammed back in the upper part of the river, that flowed away with the ebb, which, owing Mr. Vauthier.

Mr. Vauthier. to the state of the tide, had but restricted channels to escape through. In a word, as regarded the dimensions connected with the tidal part of its bed, estuary included, every tidal river formed a particular case; a species of which the different elements required harmonising, and could not be considered separately.

The Author explained very clearly the benefits resulting from the embankments of the Seine; he also showed, with much precision (save in one particular, which Mr. Vauthier would indicate), the conditions of the bay below the extremities of the banks; and from these premises he drew the conclusion that, "The importance of tidal scour in maintaining the estuary of the Seine has already been clearly manifested by the changes resulting from the reduction of its tidal capacity; and if deep water did not exist in the sea in front of the mouth of the Seine, the maintenance of the outlet of the navigation channel might be liable, before long, to entail considerable trouble and expense."

It was this proposition that Mr. Vauthier questioned, basing his objections to it on some new facts, as well as upon those known to the Author. In order to be exact, he premised that in what followed, the term "estuary of the Seine," or "bay of the Seine," would apply only to the part below Tancarville Point, 16 miles in a straight line east of the meridian of Havre, and about 18½ miles by the river.[1]

Ever since their inception the works for the embankment of the Seine had aroused the apprehensions, real or feigned, of the Port of Havre; the objection being that the silt brought down by the embanked portion of the river (of which the mass was about 80 millions of cubic yards) would injure the entrance to the port and the small roadstead to the west. It was in consequence of these fears, and when land was being reclaimed on the north of the bay, under shelter of the banks, between Tancarville and Hode Points, 4 miles distant from the meridian of Havre, that the survey of 1875 was undertaken, under the direction of Mr. Estignard. This survey showed, as might have been expected, that during the forty preceding years important changes had occurred in the bay.

To the east of the meridian of Honfleur (distant 5·8 miles from that of Havre) much alluvial material had been deposited, both north and south, in the cove of St. Sauveur, situate between

[1] It resulted from this, that the training banks (which exist for 8 kilometres, 5 miles below Tancarville Point) project, on a line east and west, 4 miles into the estuary, and are not distant from the meridian of Havre more than 12 miles as the crow flies.

Honfleur and Berville, and some alteration was noticed to the west of the meridian of Honfleur, continuing for from 1,200 to 1,500 metres beyond Havre, but on a much smaller scale. Thanks to the hydrographic chart of Beautemps-Beaupré, made in 1834, Mr. Estignard was able to trace these changes from the date named; but as to the eastern part of the estuary, owing to the absence of soundings in the above-mentioned chart, and in another made in 1853, he was only able to mark the changes since 1863, which had doubtless been very considerable in the previous period since 1834. Mr. Vauthier.

Mr. Vauthier would briefly indicate the result of Mr. Estignard's cubature of the two districts east and west of Honfleur, both as respects the amount of water permanently remaining below the zero[1] of the marine charts, and the mass of sand or silt above that level, and which he would designate emergent bottom (*fonds émergeants*).

In the region to the west of the meridian of Honfleur and north of 49° 26′ 30″, the permanent volume of water, which from 1834 to 1869 had diminished by 20 millions of cubic metres,[2] had from 1869 to 1875 increased by 32·6, or an effective addition of 12·6. In the same region the emergent bottom, which in 1869 had augmented by 25·3, had thence to 1865 diminished by 6·1, leaving the net increase 19·2. On the other hand, to the south of the same parallel, the relative figures were: for the water 28·8 and 22·8, indicating a final gain of 6. Of emergent bottom, from 1835–69 there was 3·5, while in 1875 this had diminished by 0·7; net increase, 2·8. Summing up these figures for the whole region, it would be seen that from 1834 to 1875 the permanent volume of water had increased by 18·6, while the emergent bottom had been augmented by 22. The result showed that for the whole period of forty-one years the increase of deposit was represented by 22–18·6, or 3,400,000 cubic metres. This was the result arrived at by Mr. Estignard, in Table VIII. of his report (p. 21).

Although this augmentation was small, it none the less contradicted that part of Mr. Vauthier's "Report on the Tidal Seine and its Estuary," which alleged that between the meridians 2° 5′ and 2° 15′ (west of Paris) there had occurred, between 1834 and 1875, an addition to the permanent volume of water of 22 millions of cubic metres. The discrepancy was, however, easily explained, as

[1] This unit approximates to the lowest tide ever observed at Havre.

[2] From what followed, the figures relating to volume of water would indicate millions of cubic metres, the 000,000's being omitted, 1 million cubic metres = 1,308,000 cubic yards.

Mr. Vauthier. was to be seen at p. 35 of the report in question. Mr. Estignard's cubatures related to the whole of what might have been called in 1834 the bottom, and extended to the firm shores of the bay, which had changed little, if anything, since that time. Now, since 1834, alluvial deposits had taken place between that point and the meridian of Honfleur. These deposits were only reached by exceptional tides, and did not, properly speaking, form part of the bottom at all. Well, their volume was at least 20 millions of cubic metres; if, therefore, Mr. Estignard's figures (for the north a final increase of 19·2, and for the whole region one of 3·4) were deducted, the amount of these deposits, the figures would be for the increase of the permanent volume of water 20 − 3·6, or 16,400,000 cubic metres, a difference from his own 20,000,000 too small to provoke controversy.

It was more important, however, to contest the Author's deduction from Mr. Estignard's data, "The early accumulation of deposit has doubled in the six years between 1869 and 1875." Although this statement did not refer specially to that part of the estuary comprised between the meridians of Honfleur and Havre, it would be convenient to treat it in the same way as should be done with the part to the east of Honfleur. Well, it resulted from the foregoing figures that, taking into account the simultaneous increase of permanent depth of water and emergent bottom, there was shown towards the end of 1869, as compared with 1834, to the north 45·3 increase of sand; to the south 25·3 increase of water, or a net increase of 20 of sand. In 1875 that had decreased to 3·4. Therefore the previous depositing action had been transferred to one of scouring. In this part, not only had the accumulation of deposit not doubled, but, on the contrary, it had decreased in the six years from 1869-75 at a much more rapid rate than it had increased in the thirty-five years from 1834 to 1869. He would revert to this while considering the other part of the estuary.

In the area to the east of the meridian of Honfleur, north of parallel 49° 26′ 30″, extending to the actual extremities of the training banks, the conditions were as follows, according to Mr. Estignard:—

The permanent volume of water increased 6·1 between 1863 and 1866, and diminished 2·3, thence to 1875, the net increase of water being 3·8. The increase of shore, which previously had been − 4·1, had in the second period been + 85, or a net mean of 81·3. If were added that, from the extremity of the banks at La Roque Point (where they ended in 1863) there was between that date and 1875 an increase of water of 3·8, and of deposit of 33·3, it would show to the north an increase of water of 3·8 + 3·8 = 7·6, and of deposit of 85·1 + 33·3 = 118·4, finally a net increase of deposit of 118·4 − 7·6 = 110·8. Mr. Vauthier.

In the southern part, the volume of water had diminished from 1863 to 1866 by 0·4, and from 1866 to 1875 had increased by 4·2, or a net increase of 3·8. In the same periods the deposits had increased respectively 0·5 and 53, or 53·5 in all, indicating a net increase of deposit of 53·5 − 3·8 = 49·7. Adding together these figures, indicating the changes north and south of the district east of Honfleur, there resulted 110·8 + 49·7 = 160·5; and allowing for the 20 millions of cubic metres deposited on the north side between Hode Point and the Honfleur meridian, the amount of deposit from 1863 to 1875 would be, to the north 110·8 + 20 = 130·8, and to the south 49·7, together representing 180·5 millions of cubic metres.

Mr. Vauthier found nothing to dispute in these results. He admitted also that the volume of water entering the bay above the Point Hode meridian, 3 kilometres west of that of Honfleur, might have diminished, as Mr. Estignard had calculated, to the extent of 138 at springs and 61 at neaps, or a mean of 99·5, say 100 million metres. But the figures quoted above indicated that from 1863 to 1866 the deposits below the actual extremities of the training banks were nothing at all; and that consequently it was between 1866 and 1875 that the existing alluvial deposits had taken place, but in the latter period of nine years there was nothing to show that the rate of deposit was greater at the end than at the beginning. He was even led to believe, in the absence of authentic data, that it was immediately after the completion of the training banks in 1867 that the deposits became considerable. Their rate of growth would be less as they increased in depth, and so decreased the layer of sand-bearing water by which they were formed. Some further indications tended to confirm this view.

After giving these facts, which a simple inspection of the bay might have established, it was not surprising that Mr. Estignard should find that the opinions of Mr. Bouniceau were inexact, and that the source of the considerable deposits he had shown must be sought elsewhere than in the fresh water detritus brought down by the Seine, or the natural erosion of seashore. This source was doubtless the bed of the western part of the bay and that of the open sea. If the hydrographic surveys of the bay of the Seine were not enough extended, so as to include the whole of

Mr. Vauthier. the beds supposed to be laid under contribution, it would be, however, impossible to search elsewhere for the real source of these deposits. But Mr. Estignard might fairly be asked if he had argued soundly, when, after accepting these two facts—the reduction of the bay already brought about, and the limitless abundance of the material suitable for being there deposited—he had considered the ultimate reduction of the capacity of the bay as an infallible event, bound to result sooner or later.

The unstable nature of the sand or silt which formed the beds of open seas, which the least agitation stirred up, had not been considered by Mr. Bouniceau; perhaps, on his part, Mr. Estignard had omitted the conditions under which alone this shifting material might subside in the river bed. These conditions were almost absolute quiescence of the liquid that held them in suspension, and a continuance of this quiescence in proportion to the fineness of the particles suspended.[1]

He would give a few figures showing how far these conditions should be taken into account. Mr. Estignard admitted that an average tide inclosed in the bay of the Seine would leave behind it a deposit of about 3 millimetres (0·118 inch). That engineer did not insist on the figure given, but from numerous observations and comparisons Mr. Vauthier was led to believe it was very near the truth. Now, the bay of the Seine, from the meridian of Havre east had a surface at spring tides of 160 millions of square metres, and at neaps of 115 millions, or an average of 137,500,000 square metres. It followed that the amount of solid material in an average tide was 412,500 cubic metres, which, for the 707 tides of the year, gave a volume of 291,637,500, or say, in round numbers, 300 millions of cubic metres. That granted, in considering only the period of nine years, between 1866 and 1875, the tides had floated over the bay 2,700 millions of cubic metres of solid material, of which had been deposited only 180 millions, or a fifteenth part. What had become of the rest? Brought in by the flood, it had been taken away by the ebb, and, notwithstanding

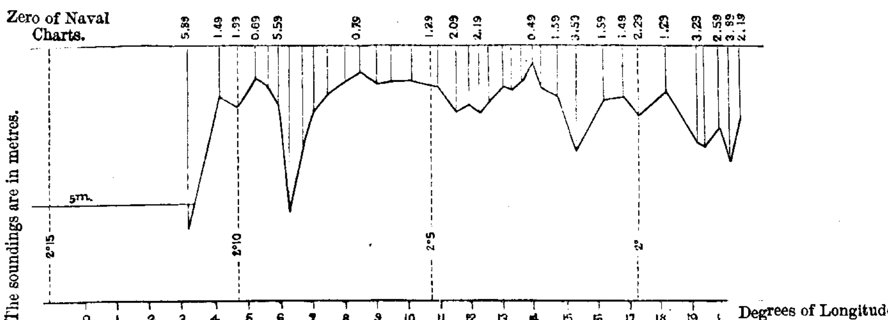
[1] Sufficiently exact observations did not exist of the time necessary for the deposit in still water of particles of various sizes held in suspension. All knew that, other things being equal, the larger particles subsided first, and his own calculation had shown that in a tranquil fluid the deposit of matter of a specific gravity of about 2·5 was very nearly proportional in time, and that the fall per second was in direct proportion to the thickness of the falling body. Water in which fine sand would be quickly deposited might remain turbid for days under the influence of impalpable matters, which the least agitation would cause to rise like clouds.

Mr. Vauthier.

the indefinite volume of material suitable for deposit, it only sufficed to prevent augmentation of the deposits, and for the establishment of an equilibrium, that currents equally powerful should sweep over the whole of what still formed the surface of the bay. Did this equilibrium really result under the conditions of the chart of 1875? Mr. Vauthier had thought so at the time he wrote his report on the tidal Seine and its estuary. A new hydrographic survey made in 1880, and of which the results were not yet fully known, seemed to indicate that he had been deceived.

The growths of the deposits in the bottom of the bay had not been relatively considerable, and the channel between the ends of the training banks and the sea had been rather improved than deteriorated. Fig. 3 gave a longitudinal section of it, which, com-

FIG. 3.



LONGITUDINAL SECTION OF THE ESTUARY OF THE SEINE FROM THE HYDROGRAPHIC SURVEY OF 1880.

pared with the section of 1875 (Annex No. 27 to his report) (Plate 3, Fig. 2) would evidence the fact, at least so far as concerned the part shown. He would add that the approaches to Havre had also improved. But the salient fact shown by the report in question was, that there should have been deposited in the lower parts of what he had called the trench (*fosse*) of the deep water between the Amfard and Ratier shoals, materials estimated at 32 millions of cubic metres. The 5-metre and 10-metre contour lines below the zero of the naval charts, instead of advancing towards the east, as from 1834, had retrograded. Could the deposit in question be regarded as a consequence of those alternate movements inherent in all matters appertaining to the sea? Or, on the contrary, did it show a failure of the erosive power of the ebb? Under correction of

Mr. Vauthier. what might be shown from the survey of 1880, Mr. Vauthier believed in the latter hypothesis; and Mr. Vernon-Harcourt, who had with such justice seen at a glance that the critical part of the bay of the Seine was that which lay between the meridians of Honfleur and of Havre, would certainly support his opinion.

On examining attentively the chart of the bay of the Seine of 1875, it was unquestionable that the deposits north and south had happily regulated the contours. Alone, the projection of the deposits in the south under the 2° meridian (west of Paris) was extremely unfavourable. It was this prominence, which violently diverted the channel in a northerly direction immediately after its issue from the embankments, that was one of the principal causes of its subsequent sinuosities. But this fault was, or should be, easily cured. On the other hand, with respect to the part below Tancarville Point, the Author shared his own opinion that the banks were not only too close, but that they were badly planned. In short, doubtless the necessity of considering at the same time the ports of Honfleur and of Havre, had rendered it necessary to give to the outlet of the bay a width greater than would otherwise have been advisable. Nevertheless, the governing defect was the insufficiency of the waters of the ebb.

Mr. Vauthier had in his report, several times quoted, suggested means of augmenting the volume of the ebb in proportion to the fault to be remedied and the effects desiderated. It had been pointed out that, with an average tide, there entered the bay at least 100 millions of cubic metres of water. On the other hand, he had shown that the volume ascending the Seine, to about 20 kilometres above Rouen, could be augmented by 30 million of cubic metres. These two amounts, differing in themselves, had an enormous difference in their mode of action. The first advanced and retired at a time when, towards the mouth, the bottom was still covered with a considerable depth of water. The second, coming from a great distance to the ascent, would abrade the bottom when the tide, nearly at ebb at the mouth, had greatly reduced the area of its water way, and would concentrate its useful effect on the navigable channel.

The profiles of 1875 (Annex 2, 3 of the report) between the meridians 2° 10′ and 2° 8′ (west of Paris) included the site of a shifting bar, which in spite of the variations in height and situation caused an almost permanent obstacle. If on these profiles were traced the average high tides of 7 metres above the zero of the charts, and the average low tides of 1·7 metre above the same datum, it then would be easily shown that the 100 millions of cubic metres rejected could only produce a much less effect on the sides of the great section, than the 30 millions of cubic metres produced in those of the smaller one. Mr. Vauthier.

Mr. Vauthier was convinced, notwithstanding the difficulties of the problem—and without disputing the advantages which might accrue from narrowing somewhat the mouth of the estuary of the Seine—that the new forces of which it was hoped to develop the action would afford an effectual solution. He would be even more confident if engineers like Mr. Vernon-Harcourt should arrive at a similar opinion.

Mr. E. WIDMER considered that the Author had clearly shown the critical situation at present existing in the Seine estuary. Consequent upon the diminution of the filling-area, the silting continued, and at several points the depths tended to decrease to a notable extent. This fact, already indicated by Mr. Estignard, had been confirmed by a hydrographic survey made in 1880 under the direction of Mr. Germain, who had recently published the results. There existed at the mouth of the Seine, nearly in the meridian of Havre, two permanent shoals, known as the Amfard and the Ratier banks. In conjunction with the north and south shores these banks formed three mouths of nearly equal size. The waters of the Seine at low tide were concentrated sometimes in one, sometimes in another of these mouths, and constituted the channel which had to be followed by vessels going up to Rouen. From 1875 to 1880 this channel maintained itself in the middle route, between Amfard and the Ratier, in spite of the frequent variations in that part of the river between the meridian of Berville and Havre. Nevertheless, Mr. Germain's soundings showed that at the outer end of this channel the greatest depth, which in 1875 reached to 19 metres (62 feet) below low water of the lowest tides, only gave 11 metres in 1880. By comparing his soundings with Mr. Estignard's survey, Mr. Germain had been able to calculate very closely the cube of the deposits formed in the five years as follows: "We may estimate at more than 30 millions of cube metres (39,240,000 cubic yards) the material deposited from 1875 to 1880, between a meridian passing through the ends of the Seine jetties and one passing 5 kilometres towards the crest distant from the mouth of the Port of Havre (which appears to form the western limit of the changes in the bottom of the estuary). It is to be remarked that nearly the whole of these deposits have occurred in a length of 6 kilometres of the channel between Amfard and the Ratier." Mr. Widmer.

The difficulty of remedying this state of affairs was well shown

Mr. Widmer. by Mr. Vernon-Harcourt. The only means of assuring in the Seine a channel of suitable depth would be to prolong the jetties seaward. But this would at once generate accretions, which would sooner or later be fatal to the ports of Havre and of Honfleur. Mr. Vauthier's plan would doubtless obviate this latter disadvantage, since his proposed banks would be almost entirely founded upon shoals, which were at present above high water of neap tides. But under these conditions such constructions would be absolutely without influence on the shifting channel, seeing that they would be established at points beyond the range of its variation.

The hydrographic survey of 1880 showed that up to that time the accretions to the shore in the neighbourhood of Havre had not caused serious inconvenience. But the enormous shoaling between Amfard and the Ratier, at a distance of less than 2 kilometres from the deepest channel leading to the port, could not fail to cause the engineers the liveliest concern. They were occupied at present in plans for changing the entrance to the port. The existing jetties, which pointed south-west, would be replaced by others established towards the north-west, in a direction where the soundings within 500 or 600 metres of the shore gave a depth of 3·5 metres (11½ feet) below the lowest tide. The channel to the port would thus be notably distant from the site of the shoals encountered by Mr. Germain. When this important work was completed, perhaps it would be time to consider the expediency of prolonging the Seine jetties. It would, however, in any case, be indispensable to make a fresh survey, and if that decided the undertaking of the prolongation, then to proceed by piecemeal, so as to judge of the effect.

At present, the situation of Honfleur was not so critical as might appear at the first blush. For many years nature had maintained near the southern coast of the estuary a false channel, which was fed at falling tide by the drainage from the banks towards the Fosse de Villerville. This channel, which ascended to a point more or less up the eastern side, was at present stationed opposite Honfleur. Thanks to this, it was easy to maintain by means of the great sluicing basin, 50 hectares (123 acres) in extent (finished in 1881), depths greater than were necessitated by the sill of the lowest lock. The depth on this sill did not exceed 7 metres (23 feet) at high water of spring tides, nor 5 metres at high water neaps.

Concerning the navigation to Rouen, as it was hopeless at present to attempt to fix the channel, attention was concentrated on its efficient buoyage. Moreover, provision had been made for the time, at present perhaps far distant, when the silting with which it was useless to contend would close the Seine to large vessels. The canal from Havre to Tancarville, being made at present through the alluvial deposits of the northern side of the estuary, would at first be constructed entirely in the interest of the river navigation, and have a depth of 3·5 metres. It had been decided that the works of art to be established at each end of the canal should from the first be of dimensions sufficient for passing vessels of a tonnage equal to those frequenting the Port of Rouen, the bed being made sufficiently wide to allow of subsequent deepening by simple dredging. The important city of Rouen would therefore be able to maintain its port by means of the Tancarville canal. Mr. Widmer.

Mr. J. EVELYN WILLIAMS remarked with reference to harbours on sandy coasts, that he thought it would be found when a solid groyne or pier was constructed so that it formed an abrupt projection to the contour of the coast, the advance of the low-water line seaward invariably followed. This was no doubt caused by the solid structure intercepting the littoral currents which carried sand in suspension, and it was only by further works or dredging that the gradual accumulation of sand would be arrested and the equilibrium of the harbour be established. The several piers in Whitehaven Harbour afforded an interesting illustration of the steps taken to acquire a sheltered deep-water accommodation. It was not until the completion of the seaward extension of the west and north piers that the desiderated equilibrium was attained. By the lengthening of these piers the embayed contour of the coast-line as affecting the harbour was destroyed, and the prejudicial effects of the littoral currents were at the same time reduced to a minimum. Mr. Williams.

With reference to estuaries, the training of the fen rivers falling into the Wash had no doubt led to beneficial results so far as the works extended, but the effective improvement was almost rendered nil owing to the training of the outfalls not being continued to deep water. At the termination of the training or guide walls the concentration of scour was diffused, and the remaining portion of the channel became tortuous and shallow. It was only by forming a direct and defined outfall to deep water, as the new cut for the Witham then in progress, or by continuing the concentration of scour to the estuary by directing and training the existing outfall channels, that the improvement of rivers could be permanently effected.

Mr. VERNON-HARCOURT, in reply to the correspondence, observed that Mr. Aitken proposed that dredging alone, without guiding- Mr. Vernon-Harcourt.

Mr. Vernon-Harcourt.

piers, should be employed for forming the entrance channels to ports. He, however, considered that jetties, carried up solid to the natural level of the beach, were advantageous if merely extended to low-water mark, which was the farthest limit the jetties of the North Sea ports could attain, in spite of prolongations. It must also be remembered, in justice to the designers of those and other harbours, that only within the last few years had it been found practicable to accomplish dredging in the open sea.

He was glad that Mr. Caland was in a position to state that the cut through Hoek of Holland was being enlarged, as its narrowness appeared to him one of the principal causes of the inadequate depth at the mouth. He had always thought that full justice had not been done to the design by the method of forming the cut, and by the work having been left incomplete; and, though his Paper had been written before the work referred to by Mr. Caland, he was not aware of any change of views in the interval. He could not agree with Mr. Cay that it would have been advantageous to put locks across the new outlet of the Maas, as he believed that, though the range of tide was small, the constant tidal oscillation up and down the channel prevented the deposit of sand and silt, whilst the river water gradually conveyed the suspended matter out to sea. He thought that a breakwater parallel to the coast, suggested by Mr. Cay for Dunkirk, and by Lieutenant Petit for Ostend, might be useful in protecting the entrance to the harbours, thus facilitating dredging operations and the entrance and exit of vessels, which was now to some extent effected by the sandbanks in front. The breakwater, however, would require to be placed near the coast, or made very long, to afford an ample protection; and he did not see how such a structure, if placed in a straight line end on to the current, could have any effect on their course. Probably, however, some concentration of the inshore currents might be gained by curving the breakwater towards the shore opposite the entrance.

It had been remarked by Commander Cialdi, that the Paper left much to be desired in the way of suggestion for the improvement of harbours on sandy coasts, but he did not venture on any suggestions, though so very competent to do so, except that jetty harbours were the only available method, whilst admitting that hitherto they had not been satisfactorily improved. Mr. Vernon-Harcourt believed that the discussion had fully made up for any deficiencies in his Paper; but he would add a few brief remarks on the general question. Four principal methods had been adopted, or proposed, for forming harbours on sandy coasts: (1) the jetty system;

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(2) closed harbour with converging solid piers; (3) an outlying detached breakwater; (4) one or more sheltering breakwaters connected with the shore by one or two open viaducts. Advocates of each one of these systems had joined in the discussion, and each system might prove the best in different localities.

The jetty system had its advantages on a fairly sheltered coast; it was economical and simple in construction, and did not interfere materially with the littoral currents and wave action when not prolonged beyond low-water mark; the inner channel and the nearer portion of the outer channel were readily kept clear by sluicing; the farther portion of the outer channel could only be maintained by dredging. The method of converging, instead of parallel, jetties, suggested in the Paper, had the advantages of increasing the scour at the entrance, of reducing the swell entering the harbour, of affording scope for dredging inside, and of projecting less abruptly from the land.

Solid piers extending out from the shore, at some distance apart and then converging at their extremities, possessed the advantages of promoting tidal scour at the entrance, of serving for refuge on exposed coasts, of protecting dredging operations inside, and of being capable of being carried into deep water. Their maintenance depended on the depth and scour at the entrance, and on the conditions affecting the progression of the shore.

An outlying breakwater parallel to the coast line would afford protection without interfering with the littoral currents; but it would require to be near the shore, or facing a bay, or of considerable length, to protect any portion of the coast from every quarter. This kind of structure, being unconnected with the shore, would merely serve as a protection to inner works.

Solid breakwaters placed in deep water and connected with the shore by open viaducts, so as not to arrest the littoral drift, appeared well adapted for sandy coasts; but the connecting viaduct, and the extent of the breakwaters situated in deep water, needed to shelter any large area, rendered this an expensive type.

It was evident that the dredgers used at Ostend, referred to by Mr. Duckham, were not large enough, though they had accomplished a fair amount of work; if the same sized dredgers were employed there as at Dunkirk and at Calais, the deepening of the outer channel would be doubtless satisfactory.

A bold scheme for the formation of a harbour on a large scale, at Ostend, had been proposed by Mr. Griffith, similar in fact to the plan adopted at Boulogne, but unfortunately in a far less favourable position both as regarded the site and the supply of materials.

Mr. Vernon-Harcourt. The situation was also much more exposed than the works on the Liffey in Dublin Bay, to which Mr. Griffith had referred. No doubt a closed harbour extending out beyond the Stroom Bank would not be injured by any progression of the foreshore for a long time, especially as the entrance would stretch far beyond the regular line of coast, and it would resemble Ymuiden or Madras on a large scale. It was really a question of policy and cost. Did the prospects of the Port of Ostend, or the national interests of Belgium, justify the very large outlay that would be necessary to form a large closed harbour at Ostend? From a merely commercial point of view, it must be acknowledged that Antwerp was by far the most important and growing port of Belgium, and that Ostend had little prospect of a similar advance, though an improvement of its approach might do much. It would require a more careful study of the very peculiar local conditions of Ostend than he had had an opportunity of making, before he could say what, in his opinion, would be the best means of improvement of that particular port; but he was inclined to think that dredging should first be tried on a more extended scale, with an enlargement and concentration of the sluicing basins, and that a detached breakwater might be designed for the protection of the entrance. Dunkirk, Nieuport, and Ostend were peculiarly unsuited for the formation of closed harbours. Mr. Keller had mentioned his proposal of converting a portion of a closed harbour into a sluicing basin by shutting it off at high water. That plan had been adopted by Smeaton at Ramsgate harbour, though not near the entrance as Mr. Keller suggested. At the present day, dredging would probably prove a more economical way of removing a bar. Curiously enough, Lieutenant Petit, who was intimately acquainted with Ostend harbour, had expressed his preference for a funnel-shaped mouth to jetty harbours, whereas Mr. Rawlinson had specially objected to this shape at Ostend as intensifying the swell entering the harbour. Mr. Vernon-Harcourt agreed with Mr. Rawlinson's view; but probably the protection of the Stroom bank had prevented much swell from entering the harbour, and the funnel shape was advantageous for the entrance and exit of vessels, though unfavourable for the efficiency of the sluicing current at the mouth.

He was glad that Mr. Pettit, the engineer at Bayonne, had added some very interesting particulars about the Adour jetties. It was unfortunate that the method of rendering the jetties close or open, by lowering or raising panels, had not been found workable, as the results of the experiment would have been of value. Messrs. Plocq and Guillain had furnished most valuable details relative to

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Boulogne, Calais, and Dunkirk, and had shown very clearly how the depth of water and the purity of the sand affected the cost and the results of dredging. He fully agreed with most of their remarks, and particularly in the distinctions they drew between the different sites. He thought, however, that the new works at Boulogne, though differing from the methods of improvement at Calais and Dunkirk, would not merely form the roadstead to the port, but, by providing a deep water entrance and preventing the inroad of sand, would be the real harbour of Boulogne, thus changed from a jetty harbour to a closed harbour, and the old jetty harbour would become merely the channel of approach to the docks. Messrs. Quinette de Rochemont, Vauthier, and Widmer, had confined their remarks to the changes in the Seine estuary with which they were well acquainted. He felt unable to reply properly to their very interesting observations, as he did not possess any information relative to the survey of 1880, not yet published, to which they referred. It appeared, however, that a considerable amount of silting-up had taken place between 1875 and 1880, and that therefore a state of equilibrium had not yet been reached. It might turn out that the maximum of deposit had been attained in 1875, and that the rate of deposit was now diminishing. Till, however, the silting up should be proved to have stopped, the shifting channel below the embankment, and the approaches to Havre, could not be considered safe from injury. Even then the prolongation of the embankments would be desirable, in the interests of the river navigation, for regulating and deepening the outlet channel; but this would occasion fresh changes in the estuary, dangerous to the Port of Havre unless its entrance could be altered, which Mr. Widmer said was under consideration. Mr. Royers was an advocate of the jetty system aided by sluicing and protected by a detached breakwater. Mr. Vernon-Harcourt agreed generally with his remarks on these points, and on the maintenance of estuaries, whilst thinking that he unduly depreciated the value of dredging. He had, however, read with some surprise Mr. Royers' remarks on Ymuiden harbour, as the preference attributed to Sir John Hawkshaw for the parallel-jetty system, over the closed harbour actually constructed, was the exact opposite to the views expressed by that gentleman about the improvement of Calais in the discussion on the Paper.[1] He had accordingly asked Sir John Hawkshaw

[1] Mr. Royers has since informed the Secretary that his authority for the statement was a report by Messrs. Stoecklin and Laroche, "Des Ports maritimes considérés au point de vue des conditions de leur établissement, &c.," p. 64 par 4. Boulogne, Simonnaire, 1879.

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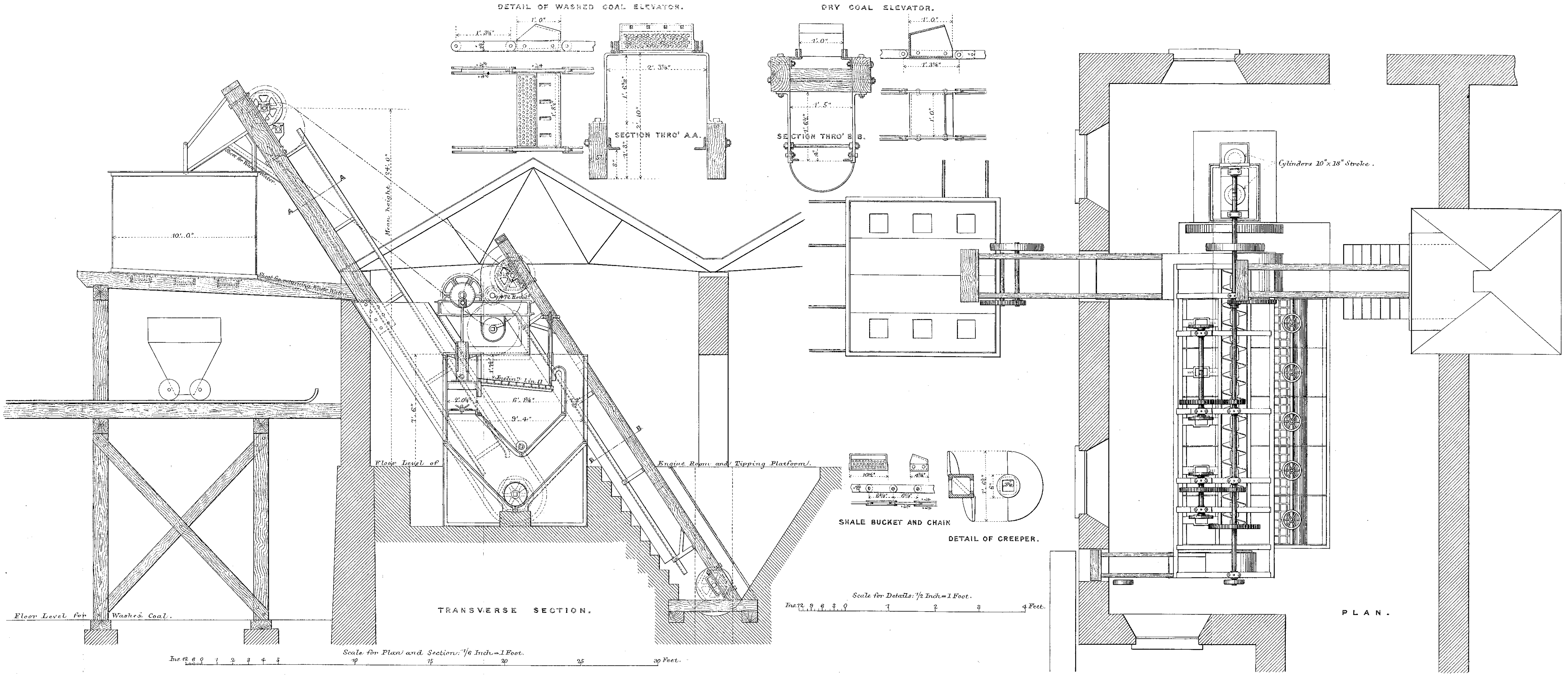
whether he had ever entertained such an opinion with reference to Ymuiden harbour, and was told that he had not. Mr. Royers must therefore have been misinformed in the matter. Moreover, the supposed reason given for the adoption of the converging breakwaters at Ymuiden, namely the greater cost of the parallel jetty system, appeared untenable, as, whatever might be the advantages of converging piers over parallel jetties in certain cases, economy in construction was not one of them. Mr. Rymer-Jones appeared to have proposed a plan for Madras harbour somewhat the same as suggested by Sir Andrew Clarke, and similar in principle to the harbours as designed for Port Elizabeth and partially carried out at Rosslare. This system of open viaducts from the shore leading to sheltering breakwaters gave a good prospect of maintenance; but in the case of Madras it would have necessitated the breakwaters being extended into a considerable depth of water. The cost, however, of this method was the only objection to which it seemed open. In conclusion he desired to express his thanks to the foreign correspondents who, by furnishing details and observations on subjects which had come under their personal experience, had so greatly added to the value of the discussion.

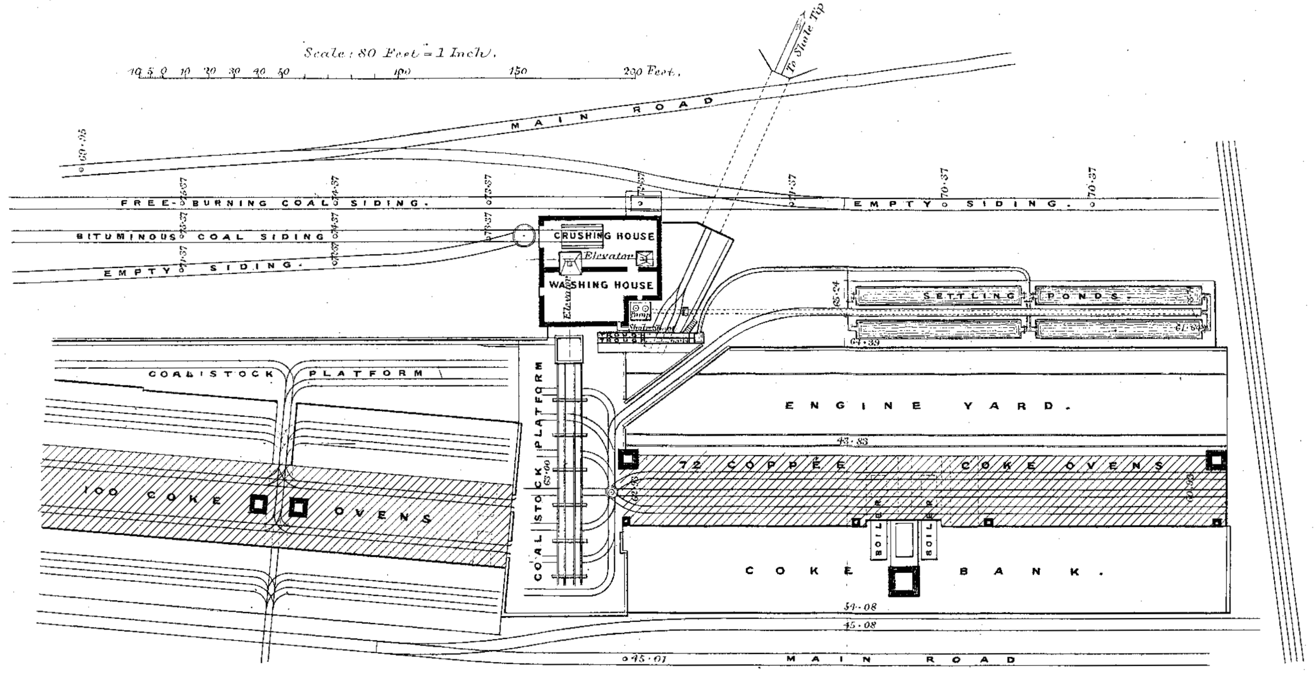
COAL-WASHING.

SHEPPARD'S MACHINE.

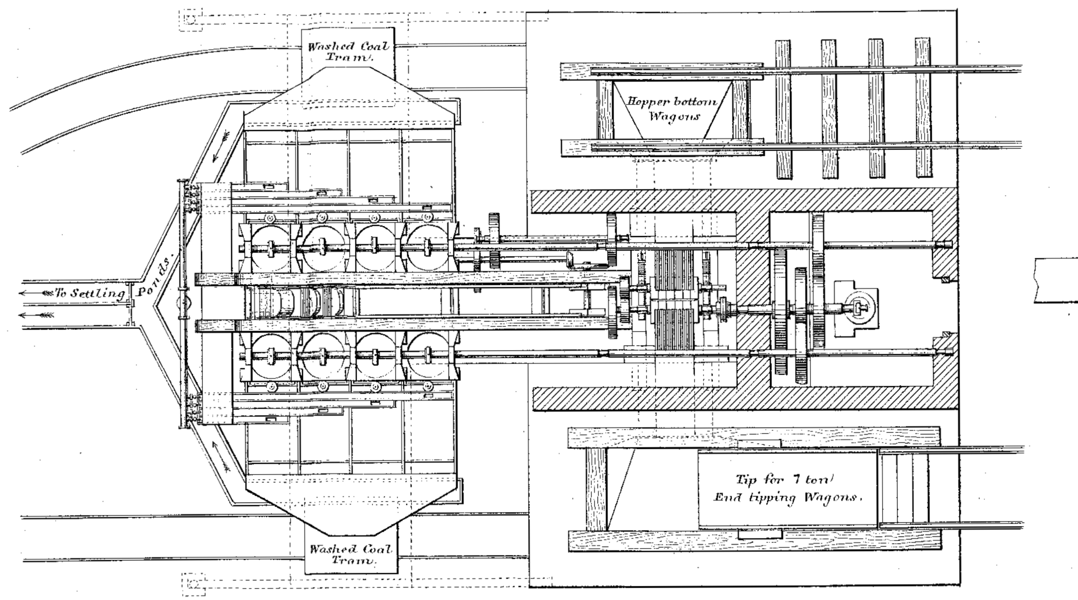


THOS F. HARVEY, DELT

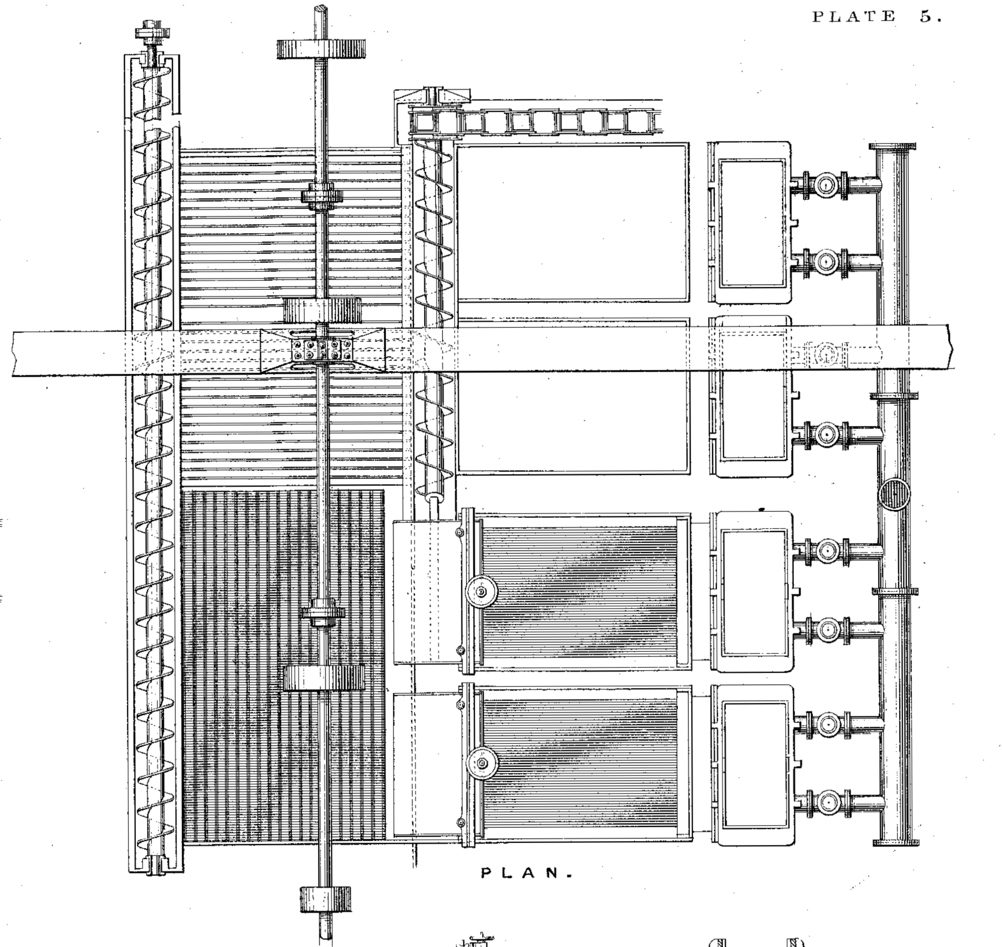
THOS KELL & SON, LITH. 40, KING ST COVENT GARDEN.



GENERAL PLAN OF NEW COAL WASHING ESTABLISHMENT, DOWLAIS.



PLAN.



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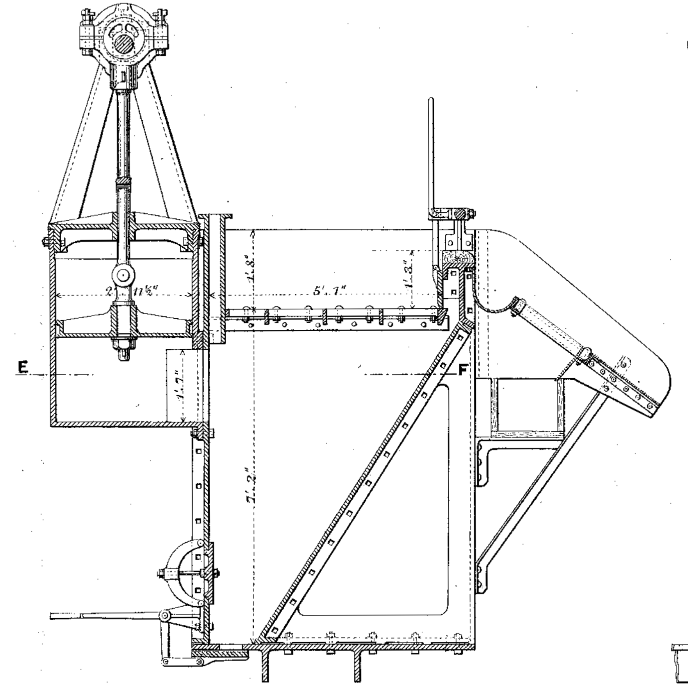
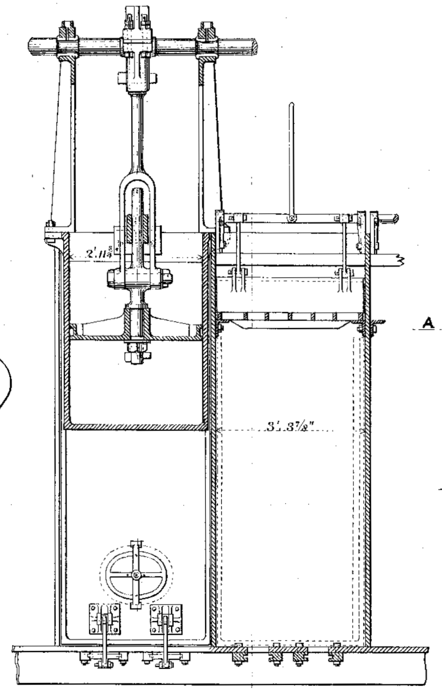
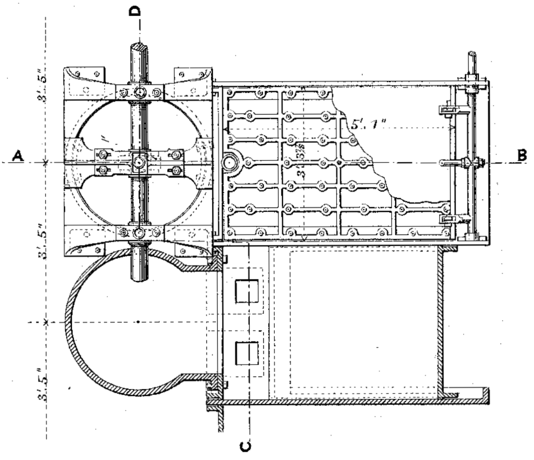


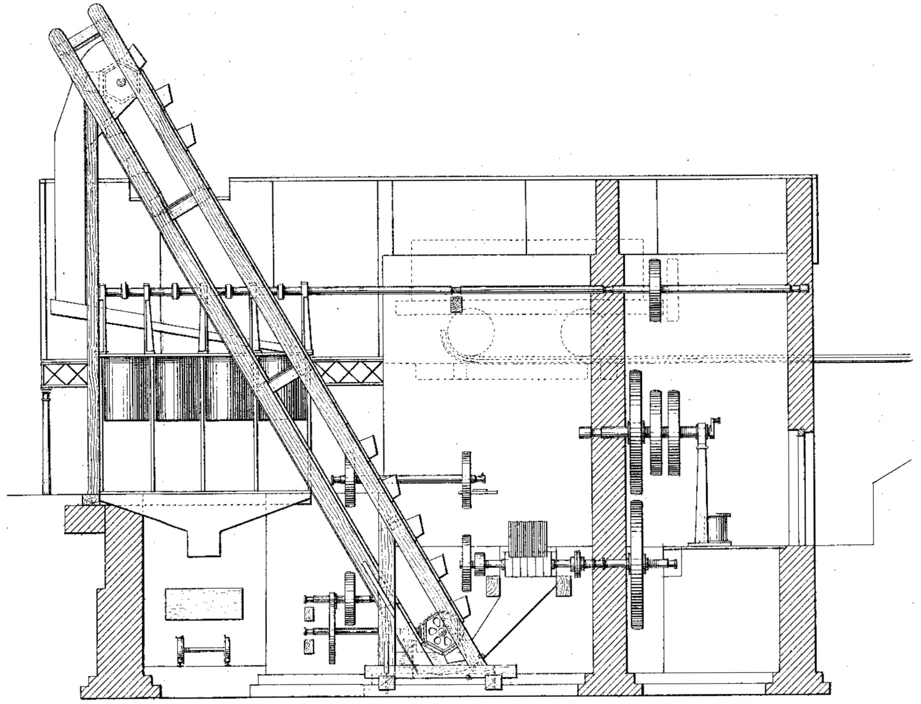
LONGITUDINAL SECTION ON LINE A.B.



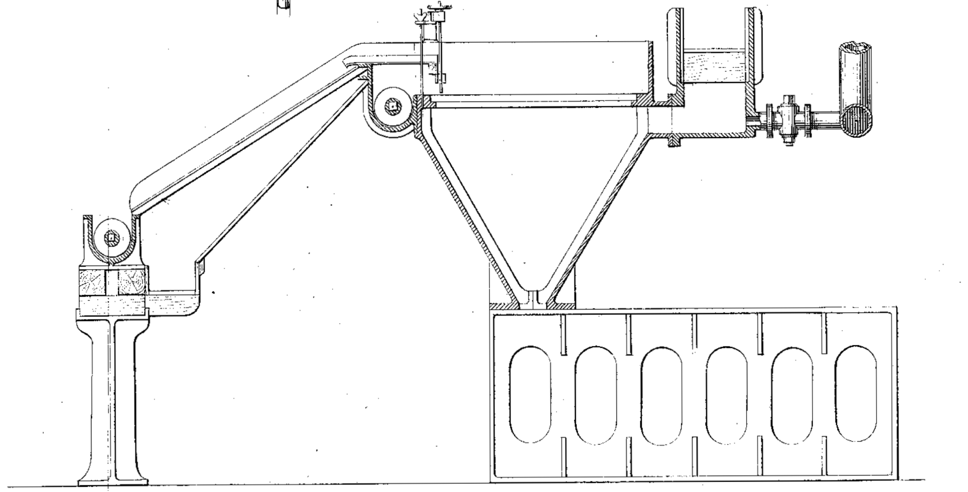
TRANSVERSE SECTION ON LINE C.D.



SECTIONAL PLAN ON LINE E.F.



LONGITUDINAL SECTION.



TRANSVERSE SECTION.

EBBW VALE MACHINE.

Scale: 3/4 Inch = 1 Foot.

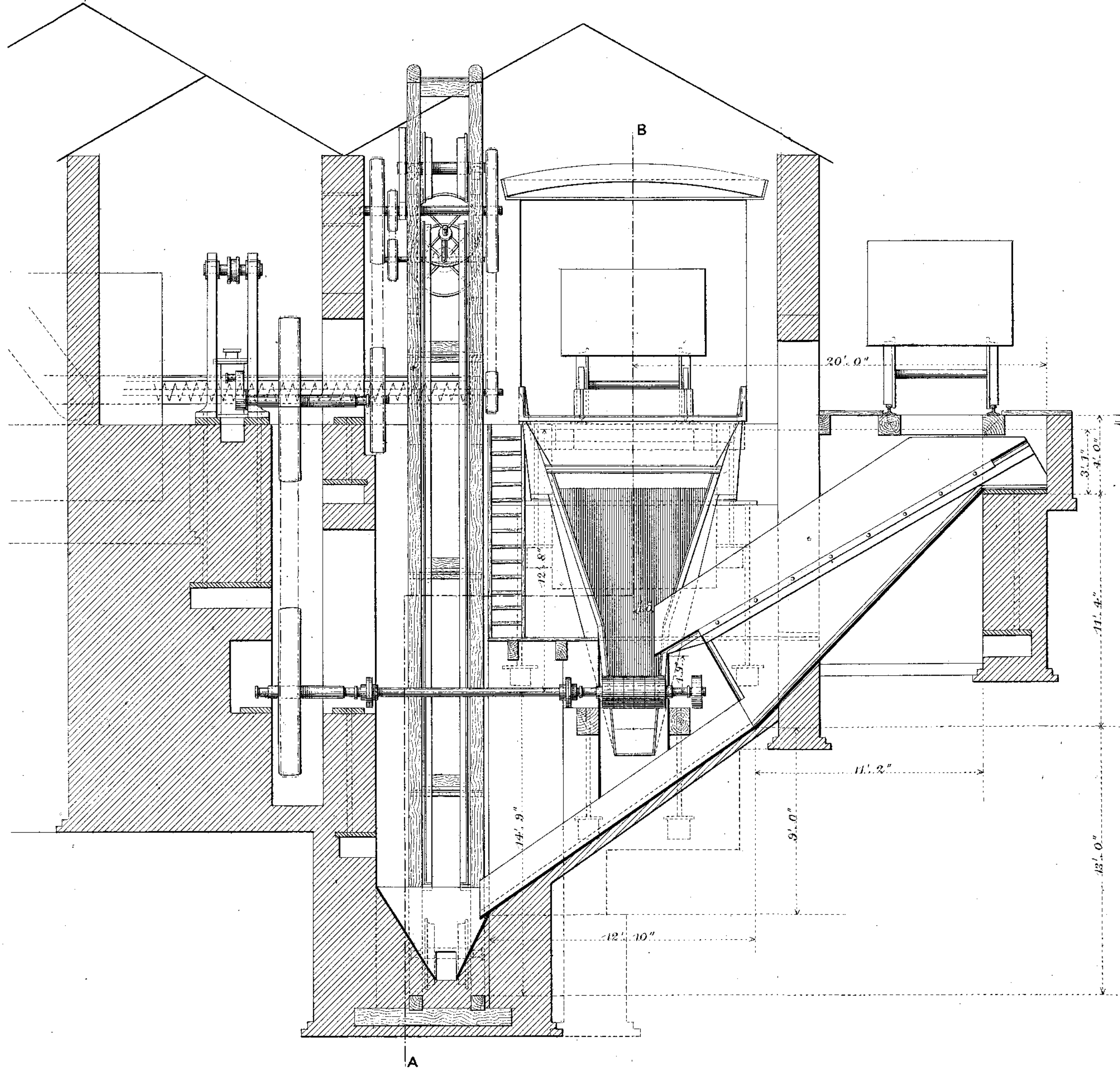
BÉRARD'S MACHINE.

Scale: 3/32 Inch = 1 Foot.

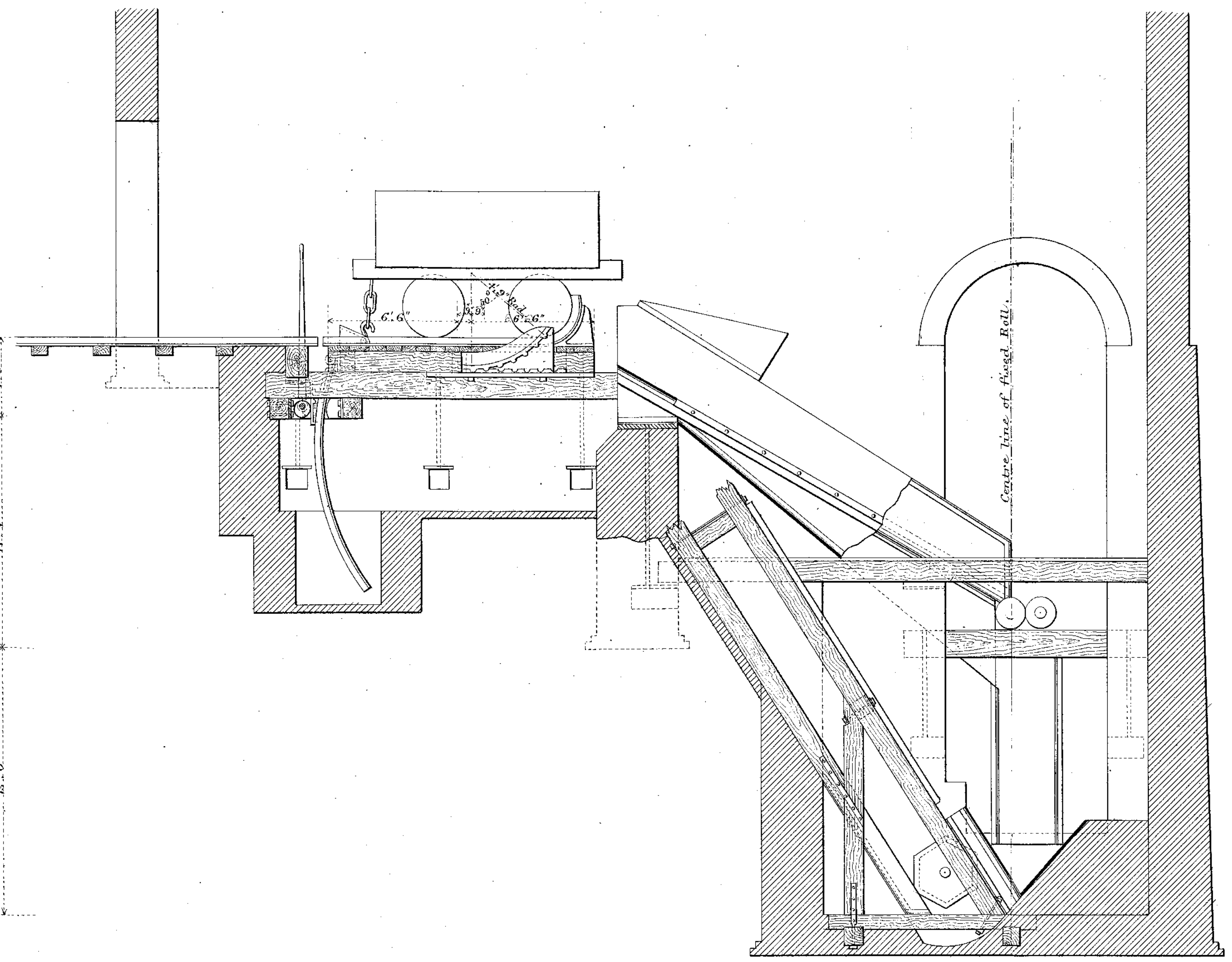
Scale: 3/32 Inch = 1 Foot.

COAL-WASHING.

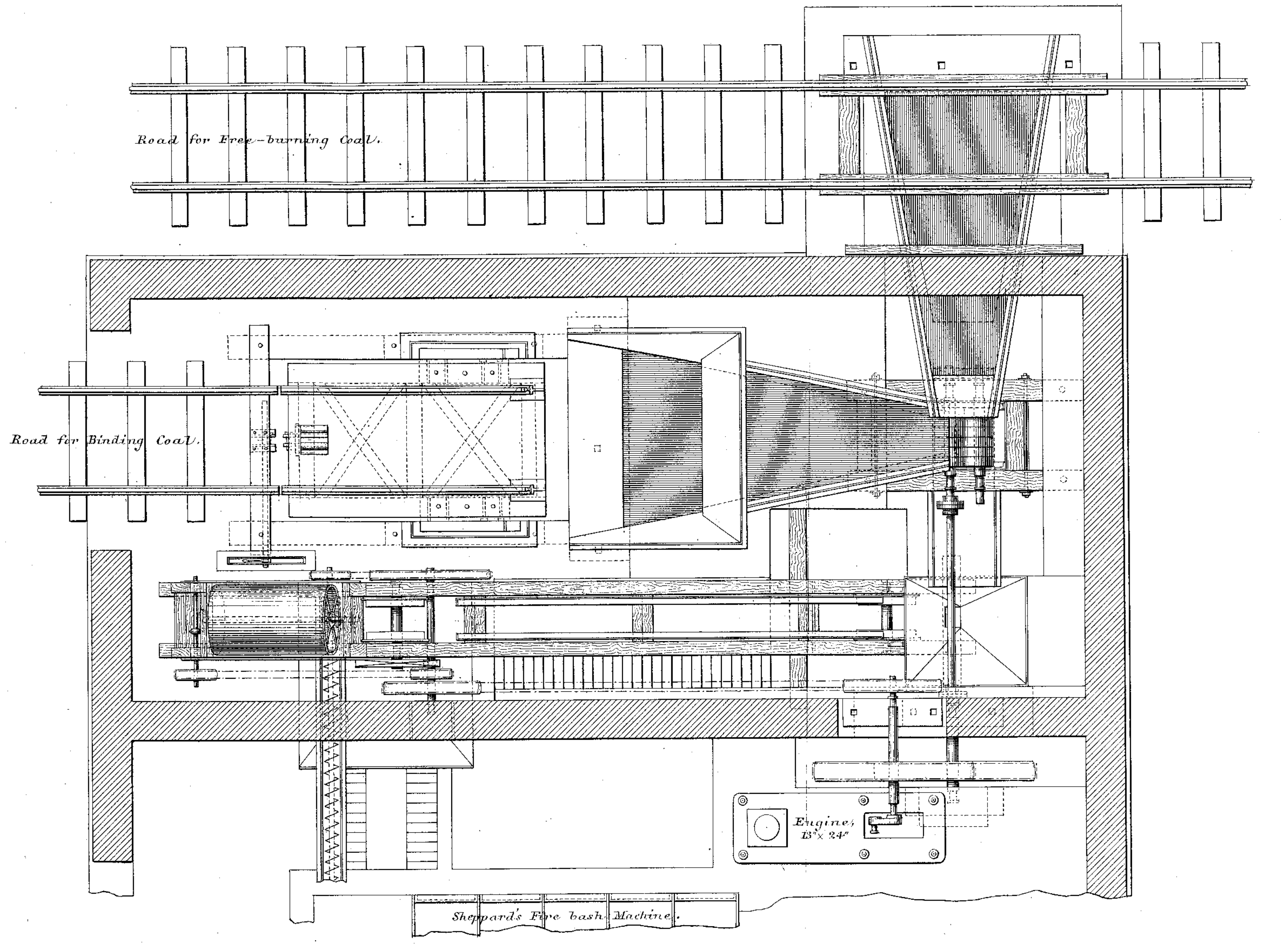
NEW ESTABLISHMENT AT DOWLAIS.



TRANSVERSE SECTION, SHOWING ELEVATOR, SCREENS, CRUSHING ROLLS, &C.



LONGITUDINAL SECTION ON LINE A.B, SHOWING TIPPING CRADLE, SCREEN, &C.



PLAN OF CRUSHING HOUSE, SHOWING SCREENS, ELEVATOR, ROLLS, TIPPING CRADLE, &C.

Scale: 1/8 Inch = 1 Foot.

THOS F. HARVEY, DELT.

THOS KELL & SON, LITH. 40, KING ST COVENT GARDEN