Discussion.

Sir John Coode. Sir JOHN COODE, K.C.M.G., President, observed that both from a commercial and from an engineering standpoint, the Paper was full of interest and of instruction. The Author was to be congratulated upon the project of 1871; it seemed that he had created a revolution in the Liverpool dock system, and one which had fully met the requirements of modern trade. The wisdom of that project had been justified by experience. With regard to the Canada Basin, the direction of the entrance, and the sluicing arrangements from the Langton and Canada basins, were admirable. The mode of working the sluices, and the protection of the outlet of the pipes by means of greenheart caps from the admission of mud and sand, had met the case thoroughly, and the proof that it had done so was to be found in the admirable working of the past eight years. The erection of cranes on the front walls and ridges of the warehouses was a new departure, and seemed likely to be followed by engineers in the future, owing to the efficient way in which the cranes performed the duty required of them.

Sir Robert Rawlinson. Sir ROBERT RAWLINSON, K.C.B., Vice President, said he entered Mr. Hartley's office in 1831, and was principal draughtsman for the last two years of his service. He considered Mr. Hartley one of the greatest masonry engineers that the world had produced, and knew of no works of the same stamp of character as the range of docks which he had designed and carried out. Sir Robert Rawlinson made the first connected plan of that range of docks when he was in Mr. Hartley's employ. He recollected the original "Old Dock," and also saw it filled up by the foundations for the custom-house. In fact he worked as a mason on those foundations when the "Old Dock" was being filled up. He knew the difficulty there was in providing sluicing power to keep the entrances of the docks clear. He also remembered the proposals as to the great docks at Wallasey Pool. The engineer contemplated a sill, 29 feet below the Old Dock Sill; but that had been abandoned; he, however, heard the evidence given in its favour in a Committee Room of the House. He would ask the Author what had been the cost per cubic yard of the class of work carried out, and why he had used Portland cement in place of Halkin mountain mortar such as Mr. Hartley used? He was satisfied that without the extensive flushing arrangement adopted by the Author, great difficulty would have been experienced in maintaining the sluices at the depth at which they had been put on the north shore, for it was a lee shore, and the deposit from the Pluckington Bank was very rapid. In order to explain the extraordinary changes in the Pluckington Bank, he might state that at the George's Basin, which had been abolished, he had known the old small floating stage at 6 o'clock on one night hard aground on a bank, where at 6 o'clock on the following evening there was a depth of 15 feet of water; the scour upon the tail of the bank having washed the sand away to that extent. He was satisfied the Author had an arduous, difficult, and somewhat dangerous piece of work in dealing with the George's Dock, because the basin itself stood upon piles. Upon one occasion of sluicing, the current was allowed to flow against the southern projection of the basin entrance, and it washed the whole of the sand and silt away from the pile heads. An extraordinary occurrence happened on the north wall of the basin, where there was a vertical sluicing culvert about 5 feet high and 3 feet wide, connected with the Prince's Dock on the north side. There had been a tide of 21 feet, and the sluices into the George's Basin had become choked. The water came into communication with the horizontal culvert, and when the tide went down, the extra pressure, which could not be more than that due to 4 or 5 feet, split the wall—a very old one—from bottom to top. The Author had, however, provided against that risk in his arrangement of sluicing pipes. There was a curious circumstance with regard to that form of sluice. At the recommendation of Mr. Hartley he became engineer to the Bridgewater Trust, and within a month a similar accident happened to the old wall of the Runcorn Canal Dock, in which there was a sluice similar to the George's Dock sluice, the old wall being split. In such cases he advocated flat in preference to vertical sluices, unless cast-iron pipes were used. Sir Robert Rawlinson.

Mr. Harrison Hayter, Vice President, observed that the Tables appended to the Paper would be of service to those engaged in dock practice. He would make a few remarks as to the masonry, which was of a somewhat peculiar kind, little known anywhere but at the Liverpool docks. The Author had shown the type he referred to in *Fig. 1*, p. 20, which accurately delineated the chief characteristics. Mr. Hayter had examined this masonry not long ago; it consisted of a rubble facework of granite, backed with concrete. The face-stones were of two kinds, about one-half consisting of small stones, and the rest of larger stones. All, however, were shallower on the bed than usual, the larger stones being from Mr. Hayter.

Mr. Hayter. 1 foot to 2 feet, or at the outside 2 feet 6 inches, and the smaller only about 6 inches or 7 inches. Each stone, whether large or small, was drafted on the edges of the face, the rest of the stone being punched with a steel punch. But the punched work never projected beyond the drafted edges, so that ships, if in contact with the wall, would meet with a smooth surface. In selecting this kind of masonry, no doubt regard was had to the quarries in the south of Scotland belonging to the Board, from which the stone was obtained. This stone, although of excellent quality, was stated to be difficult to get in square blocks, and its beds were dislocated, producing probably stones of sizes smaller than usual. Masonry of the kind he referred to required very good mortar. That used generally was made from Halkin lime, which was a lias lime, much in vogue before the use of Portland cement became general. Notwithstanding the not altogether favourable conditions, the kind of masonry seemed to have answered. Indeed, it might be expected that the Author would adopt no bond, and use no material, unless he were sure that good work would result. Sir Robert Rawlinson had alluded to the masonry, but in general rather than specific terms. It would have been well had he said something more thereon, as no one had a more practical acquaintance with the subject than he possessed. But the object Mr. Hayter had more particularly in view was to direct attention to the 30-cwt. roof-cranes in connection with the two-story or double sheds placed near the quay-edge, that was to say, 8 feet 6 inches therefrom (Plate 3). He did not think the Author had sufficiently stated the advantages of cranes running on the roof of the sheds, and of the general arrangement. The reason for this was probably because his son, Mr. A. G. Lyster, M. Inst. C.E., was the inventor of the cranes, and they were passed over in the Paper with only a few words. Mr. Hayter had examined the cranes very carefully, with the view of adopting them and a like arrangement elsewhere. The advantages of the arrangement were great. In the first place, owing to the proximity of the wall of the shed to the dock, it could be founded on the dock wall itself, and thus a good foundation be ensured for the shed wall which supported the greater part of the weight of the crane. This was the more important because generally, at the back of dock walls, there was made ground, and foundations had often to be carried down to a considerable depth. A second advantage was that the crane was in a lofty position, enabling the person working it to see into the hold of the ship, and to direct the men, and enabling him also to lower the lifting chain of the crane directly over the load to be raised, thereby saving trouble and economising time. Owing to the lofty position, also, the crane could be kept clear of the rigging of the ships, and could run to and fro clear of mooring-posts and moorings. A third advantage arose from the circumstance that there were no cranes running and swinging their loads on the quay between the shed wall and the water's edge, so that the men conveying the goods from the ship to the ground floor of the shed could work uninterruptedly and in safety. And a fourth advantage was some economy in construction, in that there was a solid foundation for the crane roads, one set of wheels running on the shed wall and the other on the ridge of the roof. Beyond strengthening the top ridge-piece, little or no alteration was required in the roofs. As regarded the distribution of weight, there was a pressure of from 12 to 14 tons on each of the wheels on the shed wall, and about 2 tons on each of the wheels on the ridge, these being the highest pressures when the crane was fully loaded. The maximum upward pull at the ridge was $3\frac{1}{2}$ tons, counteracted by ballast. Any jerk which might increase the upward pull was provided against by clipping the cranes to the rails with the usual clips. At the level of the upper floor there was an outside gangway, about 4 feet wide, serving as standing-room, to enable the load to be caught hold of and lowered. Evidently these cranes were applicable for single sheds, but they were more especially so for double sheds. In the first place, double the floor-area was obtained on the same piece of land, a desirable point where land was costly, as it so often was at dock quays. Then the lower floor could be used for the outward cargo, and the upper floor for the inward cargo; and, this being so, when a portion of the ship was cleared, the loading could be begun, so that the two operations of unloading and loading could, to some extent, go on simultaneously. The inward goods, also, being on the upper floor, could be readily lowered into wagons or carts for removal by simple appliances. From his experience in the construction of docks, he had found that, as a rule, the best position of sheds was near the quay edge, leaving a space, say from 7 to 10 feet, between the shed and the water. Probably the more common practice was to place two lines of rails between the shed, or warehouse, and the dock, and this might, under certain circumstances, be necessary. But it was impossible to take away goods from a ship without interruption if they were all to be unloaded into railway wagons. The space was too circumscribed, shunting was likely to be hindered, and it was difficult to ensure a constant uninterrupted supply of railway wagons. All goods, of course, were not admissible into sheds, but

Mr. Hayter.

Mr. Hayter. where they were, the best way to deal with them, as a rule, was at once to transfer them from the ship into the shed. In this way the ship could be released within the shortest possible time, and the goods in the shed be distributed with the requisite despatch. Of course, if the goods remained too long in the sheds, demurrage was charged. The result of the arrangement adopted at Liverpool was somewhat remarkable. He had been told by Mr. A. G. Lyster that upwards of 800 tons of goods per lineal yard of quay per annum had been passed through the double sheds. In ascertaining the capability of a dock, he had been in the habit of assuming that 350, or at the most 400 tons of goods per lineal yard of quay per annum could be dealt with; and this was the normal rate of working at a dock constructed by his firm not long ago in London, where the appliances were modern, the whole dock having a hydraulic installation, and where the provision of quay and shed was good. It was certainly always safe to assume this rate of working, and if it could be increased, as at Liverpool, the capability of the dock for certain kinds of goods would, of course, be proportionately increased. This was of great importance to owners of dock property. He was glad to have the opportunity of directing the attention of the Institution to this particular subject, because he believed hitherto no attempt had been made to lay down rules to enable engineers or others to say beforehand what work could be done in docks, except it might be in those the chief traffic of which was coals or minerals loaded from staiths or drops.

Mr. Giles. Mr. A. Giles, M.P., said it was not the privilege of every engineer to represent 6 miles of docks, with a capital expenditure of about £18,000,000, and a gross revenue of over £1,000,000; and the Author of the Paper, who had had the control of that vast establishment for the last thirty years, deserved the warmest thanks for the details he had given of the construction of those works. The Author mentioned the difficulties he had encountered, and the remedies he had adopted to overcome them. One of the foremost of those difficulties was that whereas it was prophesied, some time ago, that the sills of the Liverpool Docks could not be carried below low-water, or even anything like down to low-water, the Author had succeeded, by means of sluicing, in keeping the sills 2 feet below low-water at the lowest spring-tide, and 10 feet below the Old Dock Sill. Having been on the pier-heads of the Canada Basin upon several occasions, and having watched vessels coming in at high-water, he could only say that the system adopted there was one peculiarly adapted to the difficulties of

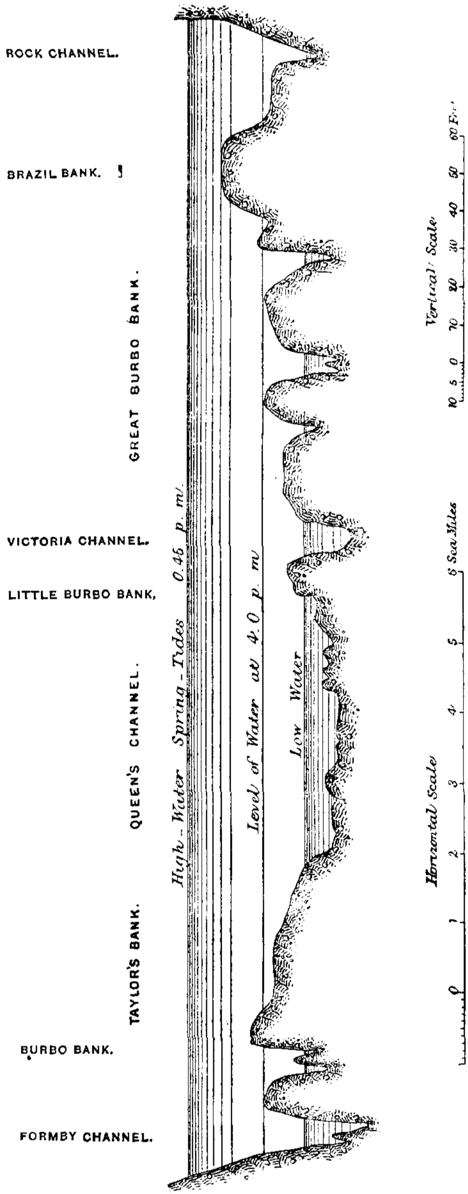
Liverpool. With the tide running up 6 or 7 knots an hour it was quite impossible for a vessel coming in to shoot the entrance. Vessels therefore went above the entrance, turned round and faced the up-current, and went in against the stream; and for that purpose the Canada Dock entrance was well suited. At the same time, when vessels entered in that way, and the docks were not large enough for the larger class of vessels to turn round, he understood that they frequently went out stern foremost. He did not know that that was a great objection; but still, it was better to go forwards than backwards. The Author had mentioned the style of masonry he had adopted for the dock walls, and it was impossible for anybody to examine those splendid works, the solidity of the masonry, and the way in which it was put together, without feeling that it was right. Where stone was cheap, as it was in the neighbourhood of Liverpool, he thought uncoursed masonry was better than concrete, and he doubted whether that system of masonry was much dearer than concrete. The greater part of the Liverpool Docks was designed when railway communication was almost unknown; but it appeared to him that if the more recent docks had been constructed so as to get better railway communication round them, it would have been more consistent with the ideas of the present day. The fact was that rapidity of motion was absolutely necessary in order to make large steamers, costing £250,000 or £300,000 each, a commercial success. Shipowners could not afford to let so costly a plant lie idle many days; they wanted to get the vessel into harbour quickly, discharge it, re-load it, and turn it round. He had himself seen large vessels in the Liverpool Docks being unloaded without the help of the railway system—loading into carts—and he thought it was not quite consistent with the practice of most ports. He believed that Liverpool was more of an emporium than a port where goods were landed and shipped for rapid transit into the interior. There were many up-town warehouses, and the owners of those warehouses were quite content to get their goods delivered by carts; at the same time, whenever a new dock was constructed nowadays, one of the first things required was that there should be railway communication round the quays. He had sketched out a dock he was just completing, which was something different to the fashion of the old retangular dock. It was in the shape of a diamond, with railway communication alongside the quays, and round the sheds, without the use of a turntable or sharp curves. Moreover, any vessel could berth herself without delay, and almost without the use of warps. The Mr. Giles.

Mr. Giles. want of railway communication was, he thought, a blot in the plan of the Liverpool Docks. Whether it was possible to get railway communication round the docks he was not sure; but, looking at the plan, he did not consider the railway communication quite sufficient. With regard to the estuary, he could not subscribe to the statement that the meandering qualities of the River Mersey, above the narrows were the cause of keeping that estuary open. It might be so; but he thought that, with the tide running into the estuary at the rate of 6 or 7 miles an hour, and out again at the same rate, if the channels of the Mersey and the Weaver were carried straight through the estuary, there would be no more chance of that estuary silting up than there was at present. He had seen it stated that the Dock Board was going to try to improve the bar, and all engineers who had had anything to do with the Mersey must have felt that the bar was the sticking point of the port. Voyages across the Atlantic were reckoned by minutes; but if a vessel arrived off the bar of the Mersey on a falling tide, it could not go in, because at the bar there was only 10 feet depth of water, while the craft drew 23, 24, or perhaps 25 feet. It was a matter of astonishment to many people that the Mersey Docks and Harbour Board, having been able to spend nearly 18 millions in making the magnificent system of docks, not only along the eastern shore, but also at Birkenhead on the western shore, had not attempted before now to try and improve the bar. It had been said that the experiment of dredging was to be tried. In his opinion it would be just as well to throw the money into the river at once, for he did not believe that any dredging of the bar would keep it open. The Author had said that it was a matter of considerable physical and financial difficulty. Mr. Giles admitted that, but he did not think it need be such a financial difficulty as some people imagined. He thought a means could be devised of forming a guide for the stream, a training-wall, which the ebb and the flood could hug on the concave side; and he believed this would scour the bar out to a greater depth. He hoped that the Mersey Docks and Harbour Board would bear these remarks in mind, for he was quite sure something better than dredging ought to be attempted.

Mr. Law. Mr. Henry Law observed that the port of Liverpool was, no doubt, in many respects unique, presenting features of great interest to the hydraulic engineer. Its external situation in the corner of two long shores meeting at a right-angle, with a copious supply of sand, was peculiar. There could be no doubt that but for the very large volume of water passing in and out every tide, it would long since have become a solid beach, as the Author had suggested. It was therefore of the utmost importance that nothing should be done which should in any way tend to lessen the quantity of water passing in daily. Compared with the tidal flow, the land water was extremely small, although he agreed with many hydraulic authorities that even that small quantity of drainage water, by finding its way through the large sandy inner estuary, did prevent it from becoming gradually silted up. Those who desired to pursue the question and the principles involved might read the evidence given, especially in the third Session in which the Manchester Ship-Canal Bill was brought forward, when the matter was fully discussed, and the position which he had mentioned was sustained. Bearing in mind the importance that no extraction of tidal water should take place, blame had occasionally been put upon those who designed the docks for having reclaimed them from the shore of the river, although they did not extend beyond the low-water line. But on further consideration he thought that a different opinion would be formed; and that it would be seen that by building the walls in their present position, by converting that which was a very irregular and unequally wide channel, and with rough shores, into a channel approximating to the *vena contracta*, theoretically a larger volume of water would be able to pass up; and such had actually been the case. A comparison, of the tidal observations taken in 1844, with more recent ones, certainly led to the conclusion that the range of tide had been appreciably increased; and when it was remembered that every foot of tidal range that could be obtained in the inner estuary meant an addition of no less than 36 million cubic yards of tidal water every tide, or one-seventeenth of the average tidal flow, it would be seen how important it was not to do anything which would diminish that tidal flow. But irrespective of the great benefit arising from the formation of what might be called the established regime in the lower part of the river, or from inducing the tidal water to flow up, the mere abstraction of water under the condition in which it was abstracted by the construction of the docks was a matter of small importance. *Fig.* 2 was a developed section of the highest ridge of the sand-banks, starting from Formby Point, passing over the bar and through the Rock Channel near New Brighton. The section showed the remains of what had been known as the New Channel, but it had disappeared, also the remains of the Victoria Channel, named after the Queen when she was Princess Victoria; and then came the Queen's Channel, which was the existing entrance to the port. The bar was indicated by a red Mr. Law.

Mr. Law.

Fig. 2.



and black buoy. It was evident on looking at the section that at high-water the water passed over such a large area that it could produce scarcely any useful effect in scouring the bar—first, because the greater part of it did not pass there; and secondly, because what passed did so at a very low velocity. Upon the model before him, by making a horizontal section at 5 fathoms below the Old Dock Sill, he was enabled to show a similar ridge, only in its natural form, to that shown upon the developed section, and it would be seen that at low-water the area through which the water could flow was very small and concentrated. It was only one-tenth of what it was at high-water, and, therefore, any abstraction of water from the upper part of the estuary, which would otherwise have arrived at the bar towards low-water, must be of a very serious character. He would remove a sand-bank in the model and thus reveal the extent exposed at high water over which the water flowed. With regard to the inner estuary, he would only refer to the way in which the channel after passing the Narrows bifurcated, one channel passing up towards Garston, and the other towards Eastham. The plan, which was Captain Graham Hill's most recent survey, showed how Dingle Point, as the Author had stated, threw the ebb stream across, and was really the cause of the Pluckington Bank, which gave so much trouble. He had also shown two sections, both starting from a point opposite the Coburg Dock; one section taken on the line of the deepest water up to Garston, and the other being a section taken along the deepest water up to Eastham. On the following Table were exhibited the Mr. Law.

SECTIONAL AREAS of WATERWAY over the HIGHEST RIDGE of SANDBANKS which EXTEND ACROSS the BAY and FORM the ENTRANCE to the PORT OF LIVERPOOL.

Time.	Height referred to Old Dock Sill.	Sectional Area in Square Yards.	Proportional Area.
High-water spring-tides . . .	+20·00	290,500	10·21
Six hours before low-water . .	+19·32	267,600	9·41
Five ,, ,, ,, . .	+15·37	236,080	8·30
Four ,, ,, ,, . .	+ 9·09	169,700	6·00
Three ,, ,, ,, . .	+ 2·36	103,250	3·63
Two ,, ,, ,, . .	− 2·64	58,485	2·06
One ,, ,, ,, . .	− 7·45	36,615	1·28
Low-water spring-tides . . .	− 9·33	28,444	1·00

areas in square yards of the channel over the ridge of sand at one, two, three, four, five, and six hours before low-water, and it would be seen that taking low-water as unit, the high-water area at a 21 feet tide at St. George's pier was ten and a quarter times as great.

Mr. W. R. KINIPPLE said that cranes of a precisely similar design to those referred to in the Paper had been proposed by himself several times over, as far back as 1873–74, and reported upon, to the Greenock Harbour Trustees on the 20th of June, 1882, in connection with some sloping-roofed sheds on jetties proposed to be erected in the Albert Harbour, and cranes of similar design to travel on the roofs had been proposed for the extensive range of sheds and warehouses at the James Watt Dock. He agreed with what Mr. Hayter had said with respect to those cranes, for in his opinion they embodied all the best features of the best cranes extant. In the James Watt Dock at Greenock he had something very similar to them now at work, except that one leg of each crane travelled on the dock coping and the other leg on the upper platform or second quay. At this dock unfortunately there was not sufficient trade at present of the class anticipated to keep the cranes fully employed. There were sheds with two stories. One he called the import quay and Mr. Kinipple.

Mr. Kinipple. the other the export quay. On the diagram showing the section of the wall below the crane, Plate 3, he noticed a rocky bottom. In the present day, when vessels had very flat floors or square bilges, it did appear to him that, unless the dock was very deep and there was plenty of water under the vessel, the bilge of the ship would most likely be indented if it settled down on the rock, especially if the rock was not plane. He had done a great deal of facing work, but not in the way mentioned in the Paper. It was simply brickwork in Portland cement, or Portland cement rubble concrete veneered or faced with granite. With reference to the angle at which the entrance to the Canada Basin was placed, he quite agreed with Mr. Giles that in a river where there was such a strong current as that at Liverpool the direction chosen by the Author was the best. On returning from Canada the steamer on which he was on board went into that dock. After crossing the bar he wondered how it would be possible to get round quickly and into the dock, knowing that the gates were to be closed in about an hour and a half. But the operation was skilfully and easily performed. The Hornby Dock wall and also the Langton Dock wall were founded on boulder-clay, which for trustworthiness he regarded as next to rock. He had spent a great deal of money in docks, having built some 50,000 or 60,000 lineal feet of piers, quays and walls; but he had never had enough money to build walls of the strength of those described in the Paper, whose bases were exactly half their heights. He should like to ask the Author why those walls had been made of such enormous strength, and what was their factor of safety. With regard to the Canada Basin, he thought the system of flushing there was very good but very costly. He had been engaged during the last eight or ten years in training the navigable channel of the Burry inlet in South Wales. There he found that by the aid of a single training-bank well up the river he could influence the channel in the lower reaches, some 3 or 4 miles away from the works; in fact, he had shifted for its full width a channel of 600 yards in about two months. No one was more astonished than himself. He went to look at the channel, and in its place discovered the fairway buoys high and dry. This extensive alteration of position was simply due to a moderate sized training-bank, 10 or 15 feet high and about 3 miles long. He thought it would be well to train the channel of the Mersey from the south on towards the Pluckington Bank on the Liverpool shore. With regard to the 6 miles of narrows, there were very few channels in the world of such depth and width in front of so important a town

Mr. Kinipple.

as Liverpool. No doubt that channel had made Liverpool. But what had become of the public spirit in Liverpool in delaying so long in attempting to deal with the bar? That bar during his lifetime had been spoken of and condemned by most men. The model exhibited by Mr. Shelford, distorted vertically to a large scale, was a very excellent one, and enabled engineers to think seriously and readily what was best to be done to obtain deep water. Any attempt to remove the bar with sand dredgers would, he thought, simply involve an annual outlay of many thousands of pounds. Some millions of tons at least must be removed before it would be possible to get 4 or 5 feet greater depth of water; and having done that it would simply mean a return sooner or later of the former evil, and then it would be necessary to repeat the operation. In his opinion the proper course to pursue was to train first and then remove by dredging what could not be scoured away. The estuary outside New Brighton indicated that immediately past that place there was a great dissipation of the ebb current, especially during its last half. It would have been better if the Author, in years gone by, instead of throwing the spare rock and stiff boulder-clay from the dock extension works into the sea some miles away, had used these materials in laying down one training-bank, say on the western side of the channel way, along a portion of the general line of the deep-water channel, extended in a north-westerly to northerly direction as need required; and the other at ½ mile therefrom on the eastern side at the mouth. He had dealt with six or seven somewhat smaller cases, and he had experienced no trouble along the entire line of the channel, except for a short distance, or length, inside of and at the crown of the bar. On the Clyde he had used rubble, and boulder-clay which was called "till" in Scotland. That till, when tipped into the Clyde, had become softened almost to the consistency of thick pea-soup, and took a flat slope. After six months it had hardened to such an extent that he had found sea-weed growing on it, and it was impossible to tell by looking at it from the pier whether it was rock or clay. He thought, if ever training-banks were laid down, it would be better in the first instance not to deposit too much rubble or big stones, but to try tentatively what the effect of two very slight training-banks would be, laid about ½ mile apart, the western one commencing at a considerable distance inside the bar, and gradually extending by a curve in a northerly direction up to and across the site of the bar as the sand was scoured away, and the eastern one with a slightly concave face to windward extending somewhat seaward of the western bank. His impression was that instead of spending

Mr. Kinipple. thousands of pounds on suction dredgers and plant of that kind, it would be far better to send down so much suitable waste spoil, drop it from some of the hopper-barges, and so practically do the work gratis and wait. He was sure work of that class would not interfere with the shipping, because, to commence with, the tops of the banks need not be higher than 15 feet under low-water mark. The banks could afterwards be gradually raised until a scoured-out depth of about 20 feet over the bar had been obtained. In his opinion this was well worth a trial, and he sincerely believed that the mode he had suggested would be effective, and the readiest, cheapest and best way to go about the work.

Mr. Shelford. Mr. W. SHELFORD remarked that the special characteristics of the Mersey had been referred to by the Author, and had been discussed pretty freely for some years elsewhere. He believed that this had given rise to a new departure in hydraulic engineering, as a most ingenious system of working models of estuaries had now been brought into use, which was conceived and carried out by Professor Osborne Reynolds. The subject had been taken up by a Committee of the British Association who had worked at it for the last two years, and from the report of that Committee, made at the Newcastle meeting last year, there could be no doubt that very valuable information and useful results would be obtained. The working models automatically represented the currents and sands in the estuary itself, so that by observing the model, the main points which affected the tidal regime could be studied. For five-and-twenty years past he had himself been in the habit of occasionally making models of the beds of estuaries, by taking the latest edition of the Admiralty charts and plotting all the soundings to a large vertical scale, say 15 to 20 feet to the inch. In that way he found that the effect of every sounding could be shown on the model, and a great many lessons might be learnt as to the condition of the estuary from the representation thus obtained of the bed of the sea. He had made such a model of the Mersey estuary, or rather of Liverpool Bay, which was the lower estuary of the Mersey. The plane of the model, which he exhibited, was that of the Admiralty chart. The dark brown indicated all above high-water, the light brown all between high-water and low-water, and the blue all that was below low-water at spring-tides. The model would bear careful study, and would be found highly instructive in many matters of detail. It would be seen that the very marked main channel coming out from Liverpool was an important channel below low-water, and that the channel to the north of it, known as "Formby Deeps," or The Old North

Mr. Shelford.

Channel, was practically silted up; also that the whole of that portion of the bottom of the sea was covered with sand and might be considered to be comparatively stable, so that there was little fear of the main channel ever taking that course again. He would also draw attention to the extraordinary character of the bar. It was a ridge of sand so marked that it looked almost like a railway tip. The ebb-tide coming from the Mersey carried its burden of suspended matter, and on reaching still water deposited its load. That had taken place and still took place, he believed, to the north, so that there would appear to be a tendency on the part of the ebb-tide to deposit its load to the north. On the south side of the main channel there was a totally different state of things; the deepest water lay to the west of the Bar Lightship; and the flood-tide came up through this deep, and made its way south-eastwards to the Mersey. The Rock Channel, well-known for navigation purposes, was chiefly caused by the flood-tide coming along the coast. Everywhere there was a tendency on the part of the flood-tide to force its way through the sands into the Mersey. The chief effect of the model was to show that the tendency on the part of the ebb-tide was to deposit its load to the north, and that there was a tendency on the part of the flood-tide to outflank the main channel and force its way into it. That was the state of things at the present time in the Mersey, and the recorded facts confirmed that view. The Victoria Channel was for years the main channel for navigation purposes. It was formed when the flood-tide out-flanked the bar in the Queen's Channel and broke into the main channel, producing a greater depth of water. This varied very much during many years, the greatest depth being in 1861, when it was 17 feet. Then the Queen's Channel recovered itself, and the depth of the water upon the bar became fixed, about six years before 1884, steadily at 9 feet. Towards the end of 1884 a remarkable thing occurred. Again the operation came into action, the flood-tide broke in by slightly outflanking the bar, and lowered it 1 foot, and the Mersey authorities recognised the change, and shifted the navigation so as to get 10 feet over the bar. The model showed that the flood-tide was trying to re-open the Victoria Channel. The Author had stated in the Paper: "It is a universally accepted opinion, by competent authorities, that any extensive exclusion of tidal water from the estuary must injuriously affect the sea-channels, and finally destroy the port of Liverpool." That was a pregnant, not to say somewhat alarming, statement. The Mersey estuary was, in his opinion, clearly divided into two parts.

Mr. Shelford. Liverpool and Birkenhead were in the centre of the estuary; above them there was the Upper Mersey, and below them was Liverpool Bay, which being chiefly under water was not often noticed, in fact all the information in the Institution on the subject of the Mersey was confined to the Upper Mersey, very little having been said about the Bay. The Author had given the quantity of tidal water in the Upper Mersey as 710,000,000 cubic yards, and had omitted altogether to give the quantity of tidal water between New Brighton and the bar. It was obvious that in considering the bar the water which passed over it, and ran 11 miles before it reached Liverpool must not be ignored. He had gone into the question closely, and had had the opportunity of using the surveys of the Mersey Docks and Harbour Board or the Conservators of the Mersey for the purpose of making his calculations, and he found that the figures given by Mr. Law agreed generally with his own, as shown in the annexed Table. The first

31 Feet Tide.	Quantity Discharged.			Mean Sectional Area of Discharge.	Mean Velocity.
	From Estuary.	From Bay.	Total.		
P.M.	Million Cubic Yards.			Square Feet.	Knots per Hour.
H.W. 12.15 to 1.45	139	178	317	2,494,135	0·4
1.45 ,, 3.0	248	189	437	1,736,000	0·9
3.0 ,, 4.0	153	152	305	1,031,000	1·3
4.0 ,, 5.0	129	104	233	573,500	1·8
5.0 ,, 6.0	71	91	162	323,000	2·2
6.0 ,, 6.45 L.W.	48	19	67	213,000	1·9
Totals . . .	788	733	1,521		

column showed the times, the second the quantities discharged from the estuary, the third the quantities discharged from the bay, and the fourth the total quantity discharged. The last column showed the velocities. It would be seen that from the time of high-water to 4 o'clock, namely, before the banks were uncovered, two-thirds of the volume of the tidal water had ebbed away at a velocity varying from 0·4 to 1·3 knot per hour. After the banks were uncovered the main channel came into operation as an ordinary channel upon dry land; and so complete was the analogy that the sectional area had proved remarkably uniform, as long as the width did not exceed 6,000 feet, after which the conditions became less stable. Some of the water, it was true, leaked out through the side channels, but the bulk went over the bar. The period of greatest mean velocity (2·2 knots per hour) was reached between 5 and 6 o'clock, low-water being at 6.45. That was not the velocity on the bar, but the mean of all the channels open at that time, and indicated on the section which Mr. Law had shown. He would sum up by pointing out that between 5 and 6 o'clock, the period of maximum velocity, 162,000,000 cubic yards only were discharged. That represented only about $\frac{1}{10}$th of the whole quantity discharged from the estuary, and of the 162,000,000 cubic yards, 91,000,000 came from the lower estuary, and 71,000,000 from the upper. Thus the quantity of water which was most important, as determining the navigable conditions of the Mersey, was that below the Rock Lighthouse, and inside the bar, which had hitherto been ignored. That was material, because it seemed to show that the quantity of tidal water passing down a river was not of so great importance as the disposition of it. If by any means a smaller volume of tidal water could be thrown into the upper part of the estuary, even though it sacrificed part of the quantity in the estuary, so as to produce a greater velocity between 5 and 6 o'clock in the lower channel, it would be more beneficial than the present great quantity which was entirely uncontrolled. In saying that he advanced nothing new, he believed he was safe in asserting that there were veteran hydraulic engineers who had founded their reputations upon it. The point which really constituted a danger to the Port of Liverpool was the want of any attempt to control the great mass of water flowing over the bar and through the sands in the bay. Mr. Shelford.

Mr. L. F. Vernon-Harcourt said that he thought there was one mistake in the Paper. He believed there was an older dock in London than there was at Liverpool. As far as he could make out, searching among different records, he found some years ago that, at the Surrey Commercial Docks, there was what was known formerly as the Howland Great Wet Dock, which was said to have been constructed in 1660, now called the Greenland Dock. It might be in the knowledge of some engineers that soon after a Paper of his on the River Seine was read before the Institution[1] in 1886, he began, on account of the great difficulties that there seemed to be in getting any reliable idea of what training-walls would produce in an estuary like the Seine, to institute a long series of Mr. Vernon-Harcourt.

[1] Minutes of Proceedings Inst. C.E., vol. lxxxiv., p. 210.

Mr. Vernon-Harcourt.

experiments, the results of which were published last year.[1] He found, first, that he was able, in taking the whole of the tidal Seine, to get fairly approximately, as Professor Reynolds had done for the inner part of the Mersey estuary, something like the state of the channels as they existed at one time on the Seine. He then introduced the existing training-walls of the Seine in the model, and obtained approximately the results that now existed. Then he introduced various schemes with different results, exhibited in the plates illustrating his Paper read before the Royal Society in February, 1889. At the beginning of last year, having completed his experiments on the Seine, he thought it desirable to turn his attention to the estuary of the Mersey. There were two points which were necessary to try and elucidate. One was what the effect of the training-walls in the upper estuary would be; and the other, whether it was possible to carry out training-works with a prospect of improving the bar. He began those experiments last year, and they had been lately completed. The results obtained were fully described and illustrated in a Paper read before the Royal Society on the 30th of January, 1890. He first made a small model of the Mersey, and did not merely confine himself to the inner estuary, because that would not have shown what the influence of training-walls might be upon the outer estuary, by which he meant the estuary beyond New Brighton. He therefore made a working model on a small scale of the whole of the estuary of the Mersey, going nearly up to Warrington, and taking it beyond the bar. He then obtained, by working the model, the shifting channels in the upper estuary; and he also got the Rock Channel, and the small in-shore channel near Formby Point. So far, because it was not possible to reproduce winds and waves in a model, the results were approximately like the actual results seen in nature. He now, with considerable interest, put training-walls in the upper estuary resembling the scheme that was proposed for the Manchester Ship-Canal in 1884. Then the model was worked for some time; and a change very soon became apparent. The upper estuary began to silt up, and the channel below New Brighton began also to silt up. There was a very distinct shallowing of that channel on account of the silting up of the upper estuary. Therefore it seemed, as far as could be judged by experiments, that the results of putting any training-walls in the upper estuary of the Mersey were what some engineers

[1] Proceedings of the Royal Society of London, vol. xlv., p. 504, and plates 2 to 4.

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said would be the case—that the channels below Liverpool would be injured. He next went on to see what could be done for the improvement of the bar, because it did not seem to follow that because training-walls were bad in the upper estuary, as he long ago believed they would be,[1] they would be bad in the lower estuary. The great point, he thought, was to arrange the training-walls so that they should not interfere with the tidal flow into the upper estuary of the Mersey. He did not see what harm such training-walls could do to the bar. He therefore put training-walls, made of strips of tin, into the model, taking them along the sides of the present channel to a certain distance, and causing them to diverge slightly so as to prevent any obstruction of the tidal flow into the narrows. Having worked the model with this arrangement for some time, the sandbank between the bar channel and the inner Formby Channel was gradually washed away, and he got a considerably deeper channel than the existing bar channel towards Formby Point to the north. He did not feel satisfied that that was absolutely the best way of dealing with the case, but it gave the assurance that training-walls in the outer estuary of the Mersey would produce a different effect from what they would in the inner estuary. Instead of leaving sandbanks in front of the outlet of the trained channel, he removed them to the depth of the bar; he then worked the model again, and got a much straighter channel, in the direction of the present channel. He was also able to get a decidedly deeper channel than the bar channel by means of those training-walls, and the removal of the sandbank, which might be regarded as dredging. From those experiments, reproducing in miniature the general results of the ebb and flow of the tide, but not any action of the winds and waves, it appeared that it would be possible by means of training-walls, carried out if necessary on both sides, certainly on the side of New Brighton, and with the assistance of dredging, to improve the channel of the Mersey over the bar.[2] Mr. Kinipple had proposed that training-walls should be put on the bar. He had suggested their being raised to 15 feet under low-water mark; but Mr. Vernon-Harcourt could not understand what he meant by that, because 15 feet below low-water level would be below the level of the bar. It appeared to him that, in any improvement of that kind, the chief point was to direct the out-

[1] "Rivers and Canals," L. F. Vernon-Harcourt, p. 257; and Minutes of Proceedings Inst. C.E., vol. lxx. p. 29.

[2] Proceedings of the Royal Society of London, vol. xlvii. p. 142.

Mr. Vernon-Harcourt. going current between the narrows towards the bar, and not necessarily to carry the training-walls over the bar itself. Mr. Kinipple had also referred to the sluicing arrangements at the Canada Basin, which, he thought, were costly; but it would be evident, with the experience on the Mersey of the great amount of accretion that took place very readily in still water, that nothing less than what the Author had carried out would be sufficient to ensure the depth of water required over the sills. Mr. Kinipple, in dealing with training-walls at Greenock, on the Firth of Clyde, had a very different estuary to deal with from that of the Mersey. Mr. Vernon-Harcourt knew them both perfectly well, and they were as different as any two estuaries could be. Greenock was in a comparatively sheltered estuary; in the outer estuary of the Mersey, especially over the bar, they were almost in the open sea. There was, therefore, a considerable difference in the exposure of training-works in the two cases. Mr. Kinipple had further referred to the latest walls in the Liverpool Docks, which he considered too costly, as being of too great a section. But as far as his experience had gone, and he had had a good deal of experience of docks in different places, he thought that clay was one of the worst materials on which dock-walls could be built. Even a silty foundation with a wall on bearing piles, gravel or sand was much better for building walls upon than clay. There was great difficulty in ensuring a stable foundation so that the walls should not be liable to slip forward. The only certain way to secure the walls from slipping forward in such a case, was to carry the foundations down considerably below the dock-bottom level. He did not think the section of the Hornby Dock wall (Plate 3), could be regarded as an excessive section, under any circumstances whatever.[1] The Langton dock wall might be rather too large; but he thought that it was not far beyond the usual strength of dock walls, especially with such a variable water-level. The Liverpool Docks might naturally be contrasted with the docks in London. The former were continuous for 6 miles. They were much more visible than the London Docks, which were placed in the bends of the river, not stretching along the river bank. The London Docks, however, were mostly considerably larger in area; for the largest dock in Liverpool, the Alexandra Dock, was 44 acres, and the Huskisson Dock, 30 acres, as compared with the Tilbury Dock, $57\frac{1}{4}$ acres; the Victoria Dock, 74 acres; and the Albert Dock, about 73 acres. The total water-area of the London

[1] "Harbours and Docks." By L. F. Vernon-Harcourt, vol. ii., plate 14.

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Docks was 558 acres, as compared with 545 acres at Liverpool and Birkenhead together. There was a disadvantage sometimes in making very large docks, because, unless a system of jetties was arranged, there was not the same amount of quay length in proportion to the area as in the case of smaller docks; but he imagined that the Alexandra Dock pointed to the conclusion that if the Author had been able to re-model the whole of the Liverpool Docks, he would not have made them so small, because they required a number of entrances, and were therefore more costly to manage than larger docks with a proper arrangement of jetties, like the Alexandra Dock, which seemed to him to be a very good type of dock. Then, again, Liverpool existed for the docks, whereas London existed for many other purposes; therefore the Liverpool Docks exercised a greater importance in regard to Liverpool than the docks of London could possibly exercise in regard to London. The London trade was larger than the Liverpool trade taken altogether. Its import trade was considerably larger, and was increasing more rapidly; but its export trade was less than Liverpool. Liverpool was situated near the manufacturing districts; whereas the trade of London was in a great measure required for the supply of London itself. As to the arrangement of the docks, owing to the great rise of tide at Liverpool, as compared with London, a different system of access had been adopted, namely, entrances and half-tide docks; whereas in London, locks had always been adopted, to enable ships to get in at most states of the tide. In many cases, however, in the London Docks, there were basins fulfilling the purposes of a half-tide dock, so that a level was formed before high-water, and allowed vessels to go straight into the basin, which could be drawn down without inconvenience to a lower level than the dock itself. There was, therefore, not so much difference between the systems adopted at London and Liverpool as might appear in looking only at the different arrangements of locks and entrances; because the basins afforded considerable facility in London for getting vessels into and out of the docks. The width of some of the entrances at Liverpool was much larger than anything in London. There were entrances at Liverpool and Birkenhead 100 feet wide; whereas in London, the largest entrances were only 80 feet wide. There were also entrances of 100 feet width at Barrow and at Havre; but he did not know of any others as wide as 100 feet. In London they had never exceeded 80 feet; and now at Liverpool they had come down to the smaller width of 65 feet, on account of the disuse of paddle-

Mr. Vernon-Harcourt. wheel steamers. Liverpool had the advantage of having all the docks under one control; whereas in London, they were under separate companies, and separate control. Undoubtedly one disadvantage in Liverpool in future would be that there would be more difficulty in dock extension than in London. Here the area of dock extension was for the present practically unlimited; whereas at Liverpool, though there were great differences in the extensions north and south, the north docks being formed on reclaimed land, and the south docks being excavated from the side of the hill, there would no doubt be increasing difficulties in forming dock extensions, not because there was not plenty of space at the north for reclaiming land for the docks, but because of the exposed nature of that site. He agreed with Mr. Giles in considering that there seemed to have been too little attention paid to the question of railway sidings in the docks. When he went over them he was surprised at the difference they presented in this respect to the small Garston Docks, which he examined on behalf of the London and North Western Railway Company in 1884. The contrast was very striking. The Garston Docks, belonging to a railway company, were wonderfully well supplied with railway appliances; whereas the Liverpool Docks were very inadequately supplied with sidings. With reference to the Pluckington Bank, Mr. Kinipple had suggested that the river should be narrowed on the opposite shore in order to remove the bank by increased scour. Mr. Vernon-Harcourt thought there might be some difficulty in narrowing the river in that way on the Cheshire side, because this would tend to interfere with the channel leading to the Sloyne. He thought the Pluckington Bank was not merely due, as stated in the Paper, to the deflection of the ebb current from Dingle Point, but that it was also due to the narrowing of the river opposite the centre of Liverpool, expanding into a wider channel above, which naturally led to deposit; and though it might be possible to remove it by narrowing the river higher up without interfering with the tidal flow, he thought it would be a delicate matter; and it was also, perhaps, questionable whether another plan, namely, that of putting docks upon the Pluckington Bank itself, would be a feasible engineering undertaking. Though opinions might differ as to the way in which the improvement of the bar should be carried out, and to what extent sidings should be introduced on the Liverpool quays, all engineers would agree that the Author had displayed remarkable ability in the sluicing arrangements for the Canada Basin, and had rendered great services to the Mersey Docks and Harbour Board in the extensions he had carried out both to the north and south for the port of Liverpool. Mr. Vernon-Harcourt.

Mr. W. R. KINIPPLE explained, in reference to Mr. Vernon-Harcourt's criticism of his remarks on training-banks, that what he meant was that they should be commenced some distance inside the bar and extended up to and across the bar, as the sand was scoured away. With regard to his reference to the Clyde, he had made no allusions to removing a bar on that river; he referred to the Burry Inlet in South Wales. Mr. Kinipple.

Sir JAMES N. DOUGLASS said that it was stated in the Paper that:—"The general range of tide must be considered as affording a comparatively convenient approach for even the largest vessels; nevertheless, as the tendency is towards a further increase in the size of ships, and when time forms such an important element of successful trading, a deeper channel would evidently be desirable. The attainment of such an end is, however, surrounded with physical and financial difficulties of no ordinary character, and though the question is kept prominently in view, no definite steps of magnitude have yet been taken towards its solution." He was sure that every member of the profession would endorse those words. At Liverpool there was a magnificent channel from the docks to the bar; that channel was well lighted and buoyed; everything seemed to be perfect for such an important maritime port, except the bar. Anything more deplorable for the interests of the port, and the shipping trading to it, could scarcely be conceived than the fact that several large steamers and sailing ships, approaching the bar of Liverpool with such weather as had been recently experienced, might have to dodge about in the most dangerous way in close proximity to each other for two or three hours, waiting for water to get over the bar. Mr. Shelford had referred to investigations now being carried out by a committee of the British Association, of which he was a member, on the action of waves and currents on the beds and foreshores of estuaries by means of working models. Sir James Douglass was also a member of that committee, and he might state that the experimental work, carried out by Professor Osborne Reynolds in the Whitworth Laboratory at Manchester, had so far been very successful, and it was establishing the important fact that the regime of such estuaries could be accurately determined by those working models. The first portion of the report of the committee was read at the last meeting of the British Association at Newcastle, and it would shortly be published. For such a case as Liverpool the most efficient and economical method to be adopted, for providing the Sir James N. Douglass.

Sir James N. Douglass. desired permanent deep-water channel between the docks and the sea, could be determined by those working models at a very small outlay, before the channel works were commenced. It was, therefore, to be hoped that the Author would be empowered to proceed with the work, and crown the success and perfection of his work at the docks by relieving Liverpool, the first maritime port in the world, of a reproach that had attached to it for so many years—the want of ready access at all times of tide and in all states of weather for the ships that were now built and were being built.

Mr. Duckham. Mr. F. E. Duckham could quite understand that those connected with dock construction would be somewhat despondent, fearing that so much having been done in the construction of docks at Liverpool, London, Barry, Southampton, and other places, there would be very little more for dock constructors to do. But it must be borne in mind that, during the last ten years, there had been an increase of no less than 33 per cent. in the foreign trade of the United Kingdom, and that increase would no doubt go on to a greater or less degree for years to come. There would therefore be docks to make, and that being so, Papers like the Author's would be of great importance to those who might have anything to do with dock-designing or construction. He considered the Author had wisely flattened the sills of the Liverpool Docks, but he thought hardly enough. He should be inclined to have the floor of the dock entrance either entirely flat, or so flat that the versed sine of the curve should not be more than 12 or 15 inches. The Author, he believed, had adopted 36 inches in an entrance of 65 feet. He would briefly explain why he should do that. In the first instance, supposing a vessel to be entering the dock at such a state of tide that it would have very little more water over the sill than the water it was actually drawing, it would have to be kept quite in the centre of the lock to be able to get through without touching one side or the other of the invert. It might be that one of the men in connection with the dock, in his zeal to get through the work, seeing that there was plenty of water on the surface on both sides of the ship coming in, would say, "We will try to get this little vessel out at the same time," and the consequence would be a jam, and it depended if the tide was rising or falling whether there would be a disaster. Another reason was that the large cargo-carrying steamers of the present day had midship sections very much like square boxes. He had one in mind which came to the Millwall Docks with a rise in the floor of only 13 inches. Fortunately its midship keel was 11 inches, but this left only 2 feet between the turn of the bilge and the level of the under side of the keel; moreover, Mr. Duckham. many of the large vessels were fitted with bilge-keels, and, therefore, for all practical purposes in connection with getting them in and out of the dock, they might be taken as being level on the under sides, so that he thought the entrances of docks should be correspondingly level or nearly so. As to the depth of the water over the sill, the Author had, no doubt, accomplished much at Liverpool in securing 12 feet of water below datum. There were difficulties in the Mersey in getting a great depth of water, especially on the north side. The 12 feet below datum gave 23 feet 7 inches below high-water of ordinary neap-tides; but he thought that wherever possible no dock should be constructed for sea-going vessels with less than 26 feet of water over the sills at ordinary neap-tides. Respecting the statement that large vessels coming up tidal rivers invariably approached the entrance of a dock heading against the flood-tide; in the Thames and other rivers the entrances of docks could be seen turned in various directions, some up and some down, and some square to the tide. There could be no doubt that, for the purposes of navigation, vessels were much more under control if they could turn their heads down against the tide, when approaching the dock entrance; and having the dock entrance pointed up the river, the vessels could get into the dock more conveniently than under other conditions; but large vessels had scarcely an opportunity of turning in the dock, and so necessarily went out stern first. It was a special convenience to them to have the entrance facing up the river, the flood-tide would catch a vessel on the quarter, turn the stern up the river, and the head thus automatically down the river in the direction in which the ship was about to proceed. The Author had referred to the number of vessels taken in at the Canada Basin during one tide. It had been said that there must be two or three entrances to do such an amount of work in the time. The only record approaching it that he had was one at the Millwall Docks twelve months ago. A fog had lasted three or four days, so that there was a large accumulation of vessels and craft wanting to go in and out of the dock. When it cleared, thirteen vessels registering 14,718 tons managed to get into the dock, and nine vessels registering 14,464 tons to get out, in all twenty-two vessels registering 29,182 tons. In addition to that, seventy-nine barges were admitted and sixty-seven barges let out, so that the total number of vessels and craft let into and out of a single lock during that tide was one hundred and sixty-eight. It was, however, to be noted that the work done

Mr. Duckham. at the Canada Basin was accomplished in a little more than two hours, while the quoted work at Millwall occupied nearly eight hours. He had referred to square sections of vessels. It had been for some time past a puzzle to him why dock walls were made with a batter. Taking the case of a wall battering an inch to a foot, the bilge of the vessel, which might be about 24 feet below the coping, would be grinding against the wall, and there would be a space of 24 inches between the coping and the side of the ship. The grinding was going on down below between the wall, where it could not be got at for repairs, and the part of the ship where damage was more likely to be done; while at the quay level there was a gap of 24 inches, which was not only a source of danger to the passengers along the quay, but a place where any packages that happened to be loose in the slings were sure to tumble into the water. That would happen, because in coming ashore they were likely to be touched by some portion of the rigging, and being loose they would easily drop. He thought if the walls were vertical (and he did not see why they should not be), it would be much more safe and convenient for dock work. He had always looked upon sluicing as unprofitable. Some 40,000 or 50,000 tons of water, which had been in the dock eight or ten hours, and had so got comparatively clean, were let out and scoured away a small portion of mud in the vicinity of the sluice outlet. But when the tide rose again, there was admitted into the dock a corresponding quantity of water, which carried with it a large mixture of mud, and generally the quantity of mud deposited in the dock by the dirty water was considerably in excess of the mud scoured away from the entrance channel. At Liverpool, no doubt, there was an exception to the rule to which he had referred. The Author had stated that a certain quantity of water had to be got rid of to lower the level of the water in the basin, and that being so the arrangement of the sluices seemed one which he did not think could be improved upon. It had effected the object wonderfully well. There was a system in practice at Tilbury Dock of forcing water down, which acted efficiently for the removal of the mud without dredging. He should be glad if the Author would give the relative cost and efficiency of the zinc roofs as compared with ordinary slate roofs. In docks where sheds were so extensive the cost of maintaining the roofs was a serious item; and if it was possible to improve upon slate roofs, it would be a very good thing. He had already said that the increase in the foreign tonnage of the United Kingdom had been 33 per cent. during the last ten years. The increase in the port of London during the last ten years was 40 per cent., while in Liverpool it was only 22 per cent. It was a question whether the non-participation of Liverpool in the average increase did not to some extent arise from the difficulty of getting ships over the bar. He believed that the word "impossible" existed in the English dictionary; he did not believe that it existed in the dictionary of English engineers; and he had no doubt that when the Author had the reins given him to carry out the work, that which had been referred to as a reproach to Liverpool and to the engineering profession would be removed. Mr. Duckham.

Mr. A. MANNING stated that the Tilbury Dock Basin was of about 17 acres, with a depth of about 26 feet at low-water of spring-tides. In that basin, as might be readily supposed, a large accumulation of mud was deposited, and the mode adopted for getting rid of it was the use of a combination of harrows and high-pressure water-jets towed from the quarters of a small tug about 70 feet in length. The tug worked about six ebb-tides in the week, and thus kept the Tilbury Basin entirely clear of mud; the water-jets were also found very serviceable for washing away the mud from the lock, and generally clearing away a great deal of mud that had hitherto been removed by spoon barges at greater cost. The matter was one upon which, during the construction of the docks, he had had the advantage of several conversations with the Author, who strongly advised him to put down a system of pipes and sluices like that adopted at the Canada Basin. Mr. Manning's objections were, first the cost, and secondly, he did not consider that sluicing from the water in the dock, with a head of only 18 or 20 feet, would be sufficiently effective in 26 feet depth of water. It was very different when there was only 3 or 4 feet depth of water over a concrete bottom, as in the Canada Basin. He therefore determined to wait and see the result of the accumulations of mud, and apply some ambulatory system of sluicing instead. He did not know that the method adopted was an original idea, but the gentleman who superintended the work under him at the time was strongly impressed with the value of using high-pressure water-jets. Previously chain harrows merely had been used. He was bound to say that the addition of the water-jets added materially to the success of the operation. It might be roughly stated that the system accomplished in six tides more than would be done in twelve tides without their aid. The water-jets, he believed, worked at about 80 lbs. pressure per square inch, having an effective pressure of about 60 lbs. at the bottom of the dock. A great deal had been said about the absence of railway sidings Mr. Manning.

Mr. Manning. at the Liverpool Docks. An important factor in determining the arrangement of docks was a consideration of the trade of the town in which they were placed. He had given the subject of railway accommodation primary consideration in the arrangement of the Tilbury Docks, which docks were like a large railway goods yard. In arranging the sidings of docks great care should be taken that every quay should be approached by workable curves, and it should not be necessary to have turntables in any place for getting trains to and from the quay side. At Liverpool the railways coming into the town were not very conveniently situated, even if the system of the merchants there permitted of any large extent of railway business being done; but it was clear from the system adopted by the ship-owners of discharging their own ships, and the merchants warehousing their goods in their own warehouses in the town, that an elaborate railway system at Liverpool would be practically thrown away. From what he had seen, he thought the railway accommodation provided at Liverpool was far in excess of any use that was made of it. Credit should therefore be given to the Author for having arranged the docks in a way that suited the character of the trade of the town. One matter had always been a subject of regret to him since he first saw the early part of the works of the north end extension—namely the question of depth. Considering the facility with which the bank had been moved by the sluicing arrangement, it would have been very desirable to make the entrance into the Langton Dock and the Canada Basin at least 5 feet deeper. He did not believe there would have been any practical difficulty in keeping the bank clear, even by the arrangement of sluices which the Author had so successfully adopted. It was undoubtedly most objectionable and most detrimental to the business of a great port like Liverpool, having weekly services of Atlantic liners, when presumably every other week the vessels were unable to enter the dock by reason of the low high-water neaps, or could not finish their loading in the docks for fear of being beneaped on the day they had to sail. It involved a great deal of most unpleasant and dangerous work in commencing the discharge and finishing the loading of big ships in the Mersey, and he hoped the time would come when a new entrance into those splendid docks at the north end would be made, with a sufficient depth to admit of vessels being docked at high-water of neap-tides—which could not be done at the present time. Mr. Duckham had referred to ordinary neaps as giving 23 feet 7 inches at the sill. He believed that the low neaps given in the Tables were only 20 feet 8 inches—a depth manifestly useless to vessels loading to 26 or 27 feet. No doubt great importance had been attached to the question of dealing with the bar of the Mersey. He only desired to point out that unless some scheme could be adopted by which the bar could be removed, so as to give from 4 to 5 fathoms of water where now there was little more than 1½ fathom, it would scarcely be of practical utility to Liverpool. Nature for many years, he might say for many centuries, had maintained the depth of water over the bar in the Mersey at very much its present condition. True, it had shifted and required constant attention. But, according to the oldest records of the Hydrographer's office to which he had referred, there did not appear to have been any material difference in the depth of water on the bar. Of course training-walls would to some extent tend to increase the scour; but there was one point that might be gathered from the study of the best charts of the Mersey estuary, as being a very important consideration, and one which he thought operated materially against the success that some engineers anticipated from the construction of training-walls, namely, the long distance outside the bar at which the bottom of the sea was nearly level. He believed that from the present bar a depth of 10 fathoms of water was not reached in less than 8 or 10 miles. It was therefore almost certain that training-walls would merely have the effect of shifting the bar further out, and that they might be extended for 8 or 10 miles before the bar was effectually dispersed by their action. Of course engineers naturally liked to see large corporations finding money for interesting experiments; but he thought the question should be approached with very great care, and he was not at all sanguine about the result. Mr. Manning.

Sir JOHN COODE asked if Mr. Manning could state the length, breadth and depth of the deposit outside the dock entrance at Tilbury. Sir John Coode.

Mr. MANNING said it was a daily deposit. The fresh deposit each day would only be about 1½ inch or 2 inches; it did not extend into the river beyond the range of the pier heads. Deep water was reached a very small way outside, and the mud soon got dispersed. Mr. Manning.

Mr. A. C. HURTZIG said that the Author had emphasized the importance to the welfare of the port of Liverpool of having docks with deep sills, and proceeded to show how necessary it was to scheme an arrangement by which the depth on the sills should be maintained after the docks were constructed. He had fully described the interesting arrangement that he had brought out for those Mr. Hurtzig.

Mr. Hurtzig. sluices. When the north extension works were under construction, Mr. Hurtzig had an opportunity of going through the sluices on one or two occasions, and he was much impressed with the magnificence of the work, and had watched their results with interest. The Author had stated that the estimated cost of the north extension works was about £2,727,000. He should be glad to know the estimated cost of the same works, supposing the sluices had not been constructed, and the walls had been made solid in the usual way. The Author had said that he declined to resort to such "expedients," as he had called them, as dredging. Deep sills were as important to other ports of the country as to Liverpool, and deep sills had been elsewhere constructed. Mr. Abernethy, Past President, had constructed the Alexandra Dock at Hull, whose sill was 14 feet below low-water of spring-tides. In making the approach to that sill, he had dredged an artificial channel through a hard clay bank, to the extent of about 30 or 35 acres. The depth of the water at the commencement of the works was 2 feet at low-water of spring-tides, and he had dredged it to 12 feet at low-water of spring-tides. Since the opening of the dock in 1885, one single-ladder dredger had been at work at the entrance. The depth of the water was 34 feet at high-water of spring-tides, and 28 feet at high-water of neap-tides, and the annual cost of dredging the artificial channel over the 30 or 35 acres had been about £4,000, including everything. The area of the Canada Basin was $9\frac{1}{2}$ acres, and of the trumpet-shaped entrance $3\frac{1}{2}$ acres: in all 13 acres. He might point out that the Humber at Hull was quite as exposed as the Mersey at the Canada Basin. There was a fetch of 14 miles down towards Grimsby and 21 to the Spurn. The river was nearly 2 miles wide opposite the entrance. The seas there, although not reaching the 15 feet above high-water mark which the Author had referred to, were very heavy on occasions, and the dredging in the Humber, he imagined, was as difficult as it would be in the Mersey. The cost of £4,000 a year capitalised would be £100,000. The Author had only 13 acres to deal with, and if he had resorted to such a plan as dredging, he would probably have saved a quarter of a million of money by not constructing the sluices. He did not say that the sluices were not efficient, or that they were not a splendid monument of the Author's engineering skill; but financially he believed they were not what they might be. He wished to refer to one other point with regard to the Pluckington Bank. Mr. Shoolbred in 1876 had read a Paper before the Institution on the estuary of the Mersey, in which he gave three or four outlines, and capacities, of the Pluckington Bank at different times for different years.[1] It would be, he thought, of value to the Institution if the Author could supplement his Paper by the most recent survey of Pluckington Bank, showing its present condition. He had stated that the bank was due to the diversion of the tide by the rocks at Dingle Point. If that were so, how would it account for the increase of Pluckington Bank? Such increase had been progressive and almost corresponding with the continuation of the walls down towards the mouth of the Mersey, which, he thought, had deflected the flood currents to the Cheshire shore more and more, in consequence of the smooth and advantageous channel which they formed for the tidal current. That increased deflection of the tide, he thought, was the cause of the increase of Pluckington Bank, whatever might be the cause of its origin. It would not be possible, perhaps, to remove the Pluckington Bank. The Author had met the case in an ingenious way by having a continuous chain of docks from the south end, which rendered it unnecessary to approach the older docks by crossing Pluckington Bank. That was perhaps the best way out of the difficulty, but it would be interesting to know what was the most recent condition of this Bank. He could not say much as to the bar. The interesting and splendid model which Mr. Shelford exhibited gave an excellent idea of the subaqueous condition of the bed of the estuary. Whatever was done would of course have to be conducted on a large scale, but the principle to be borne in mind was that the tidal water which accumulated in the upper estuary should be constrained to go out from the river through one channel only. Therefore, all the subsidiary channels through the different Burbo Banks should, if the engineering question alone were considered, be rigidly closed in some way, and something should be done to prevent the diversion of the main channel into the old Formby outlet. In that way the effect of the sea waves in pounding up sand and forming a bar would be largely counteracted; the bar would be sent much more to seaward, if not entirely dispersed. No doubt the financial difficulties were very great, and there were the vested interests of the coasters to be considered, so that the whole subject should be approached with the greatest caution. Mr. Hurtzig.

Mr. R. Capper said that the Paper was so explicit that he, as one who was apprenticed to the management and working of docks in London, felt great difficulty in finding any question to ask respecting it. The Author had given the length of the double Mr. Capper.

[1] Minutes of Proceedings Inst. C.E., vol. xlvi. p. 29.

Mr. Capper. storage sheds and the area, but he had not given the cubical storage capacity per lineal foot of quay frontage. He saw no limit of safety for storing on the upper floor, so that he could not work out the cubical capacity himself. If the Author would kindly give that information, it would be very valuable; and it would also be interesting if he would supply a diagram of Toxteth Dock sheds, showing an actual distribution of a ship's cargo upon the floors, because he thought that the horizontal area was only about equal to the vertical area of the cubical contents of the ship. With reference to the powers granted by the Act of 1873, and the extension of the construction of the works over a period of eight or nine years, would the Author state what percentage had had to be added to the actual cost for interest during construction? With regard to the trade of London and Liverpool, nearly all the vessels that went into the Mersey entered the docks, but that was not the case in London. It was stated in the Paper that the revenue from all sources derived from 18,000,000 tons of shipping was £2,500,000; this was 2*s.* 9*d.* per registered ton. It was well known, however, that the gross income of the docks in London per ton of shipping was 10*s.*

Mr. Williams. Mr. J. EVELYN WILLIAMS said that, however complete these great dock works might be, he was of opinion that no time should be lost in sweeping away the bar, which formed practically the sill of the entire Mersey Dock Estate. It was stated that the navigating depth over the bar at lowest low-water of spring-tides was 10 feet, and that the range of the tide was 30 feet at springs, while neap-tides had a range of 10 feet, with a high-water 20 feet above low-water of springs. Thus the depth of water on the bar at high-water of spring-tides was 40 feet, and at high-water of neap-tides 30 feet. It seemed obvious from this, that the normal level of mean low-water was 15 feet above the bar; therefore, to allow modern express Atlantic liners to run up the Mersey, even at mean low-water level, would entail the lowering of the bar about 10 feet. He was well acquainted with the bar, and had sailed over it frequently under all conditions of weather and of tide; and he felt sure that if its removal should be decided upon, success would be assured under the local knowledge and guidance of the Author of the Paper. He questioned, however, whether the removal of the bar could be permanently effected by dredging operations alone. In so open and exposed a position it might possibly happen, during a heavy gale, that the works of a year would be obliterated in twenty-four hours. To afford a permanent deep-water channel, he was inclined to concur with the opinion as to the necessity of closing the secondary and minor outlet to the sea locally known as the "Rock Channel." This work, he thought, would be less difficult than the closing of the old sea channel of the River Witham, which he effected only a few years ago. It would also, he thought, be necessary to close any minor channels lower down, so as to concentrate the scour in the main channel over the bar, and at the same time afford protection to the dredging operations within. Mr. Williams.

Mr. J. W. Grover believed that if the stream in the estuary could be confined to one channel, instead of being allowed to spread about over a number of channels, force would be obtained to scour away the bar. The difficulty was how to do it. Some twenty-five years ago he had seen an extensive system of training-walls carried out at the mouth of the River Maas, for a small sum of money. The Dutchmen formed mattresses of osiers, which were taken down by barges, filled with stone. When they got them into position they threw the stones upon them and sank them. The same thing was done in the Wash by Mr. Wheeler about fifteen years ago on an extensive scale, though with this great difference, that he did not tie the fascines together, but simply threw them over and clay on the top of them. But although the depth of water was nearly 20 feet, the works were not in an open sea-way like those at the mouth of the River Maas. He would suggest whether it might not be possible to carry out works of that description at Liverpool. Five years ago Mr. Grover had carried out some embankments and sea-works at the mouth of the River Dee, and he used faggots very largely, for which he paid 12*s.* 6*d.* a hundred. So far as his experience had gone, he believed that the cost of a work of this kind need not exceed 2*s.* 6*d.* per cubic yard. The mattresses were made smaller and smaller as the work gradually emerged out of the water. The cost of the works on the River Witham was only about 1*s.* 8*d.* per cubic yard. He therefore thought that his calculation was not very far from the mark, especially when it was considered that, instead of using clay, he should propose to use stone. No doubt the Rock Channel, which was a-wash at low-water at the mouth should be closed up. Formerly it was the channel connected with the Dee, and coasters, ships, and boats used to go along it; but now there was a large bank, called Hoylake Bank, at the mouth of the Dee on the north side at the end of the channel, which he believed stopped up the passage so far as any practical utility was concerned. In the same way if the Formby Channel on the north side were stopped up, the power of the ebb would be sufficiently strong to carry away the bar. Mr. Grover.

Mr. Walker. Mr. CHARLES R. WALKER said, that while acting as Resident Engineer for the Harbour Commissioners of the Isle of Man, he frequently had to visit Liverpool, and consequently he well knew the violence of the storms on the bar of the Mersey. He was afraid that training-walls of either rubble stones or of weighted fascines would not be able to resist the force of the sea in such an exposed situation, and that the stones would be washed into the channel, to be afterwards removed at great expense. He believed the best plan would be to deepen and improve the present channel. If the sand, after it was dredged or pumped, had to be taken away by barges, he thought the progress of clearing out the channel would not be very rapid; but if the sand were disturbed by harrows drawn by a tug during the ebb-tide, the out-going tide would readily clear it away. He considered that the method of propeller sluicing, recommended by Mr. R. A. Habersham, for the removal of shoals in the Columbia River, and described by Mr. H. Hawgood,[1] well worthy of trial. It had proved effectual in that case, and he was persuaded that an experiment carried out on the Mersey bar in the same way, as detailed in the Paper referred to, would give a favourable result. With regard to the removal by sluicing of the silt at the Canada Basin and entrance, although this was evidently done by the water drawn from the docks, which necessarily reduced the head at spring-tides, yet as it was stated that as much water as possible must be retained to give flotation to the vessels in the inner docks at low neap-tides, perhaps the Author would kindly explain how he then obtained the water for sluicing. Possibly this might be procured by pumping water from the river into the docks by a set of large centrifugal pumps. He did not think that a better or cheaper way could be devised for clearing away the mud than that adopted by the Author, whose idea of utilizing the surplus water in the docks at spring-tides for the purpose of sluicing, would, he considered, be of much value in the future designing of docks for localities where there was a great rise and fall of tide.

Mr. Lyster. Mr. G. F. LYSTER, in reply, said that Sir Robert Rawlinson had gone back to ancient history, and had referred to the late Mr. Jesse Hartley, than whose works, particularly those in masonry, there never were better examples of sound engineering. Sir Robert Rawlinson's name too was well known amongst the engineer's staff at Liverpool, even the youngest of whom looked up to the position which he had achieved, and attempted to follow so excellent an example. The masonry adopted in Liverpool varied in kind. In the river

[1] Minutes of Proceedings Inst. C.E., vol. lxxxiii. p. 386.

walls, and parts exposed to the heavy action of the sea, it was of a massive and cyclopean type. The stones were irregular in form, but fairly well bedded, and jointed from 8 to 9 inches back from the face. The face was known as "rock face," and the whole was set, not as Sir Robert Rawlinson seemed to think, in cement, but in lime mortar. It was pointed 1½ inch in from the face with Portland cement, the joints being all exceedingly well kept up. The second type was that comprised in the masonry of the dock entrances, chambers, locks, nibs and pier heads. That was also of the same class as the outside work, but with the difference that the cyclopean character was not so carefully carried out as regarded size. As Mr. Hayter had indicated, a considerable amount of small stone was used, but always with a sufficient number of large stones to insure good bond; it was "chisel-drafted" and "punched" on the face, also set in lime mortar, and backed up with large masses of red sandstone. The masons employed were very ready at that class of work, and were able to put it together rapidly, without the extreme cost which might be expected by a stranger looking at the completed work. The inner dock masonry was composed as a rule of red sandstone; it was all square on the beds and joints, and it was also pitched and dressed on the face, so as to present an even surface to the rubbing of the ships. It was coped with granite in all cases. The granite was irregular in form, sometimes bonding two or three courses into the body of the work, and at other times stretching along three or four courses. He had adopted the cyclopean class of masonry very largely at Guernsey, because the granite in that island was of a dislocated character, not like the Cornish granite, but only obtained in irregular blocks, somewhat similar to that which he got from the Mersey Docks and Harbour Board's quarries at Kirkmabreck, Kirkcudbrightshire. The Kirkmabreck granite work might appear costly at first sight, but it was by no means so considering the circumstances. Quarrying granite in large blocks gave an opportunity of getting a considerable quantity of the smaller material which was used for pinners, which Mr. Hayter had referred to, and which, as a rule, were deeply bedded in the body of the wall. There could be no doubt that this class of masonry served its purpose admirably, presenting a hard surface for vessels to rub against; and that surface was obtained as cheaply as possible by the use of granite in any shape that came to hand, and without much labour on it. There could be no question of its durability; none of the stones ever got displaced, and the wall so built practically required no repairs. At the quarries, stone, such as was suitable for paving, was all set

Mr. Lyster.

Mr. Lyster. aside and formed into setts, which were brought ready dressed to the quays. Though it was not of the hornblende character, it was hard, and made an excellent pavement. The sandstone was procured from Runcorn in large ashlar blocks. He did not use much of the ashlar, but whatever he did use was delivered at a cost from 7*d.* to 8*d.* per cubic foot. The large backing was delivered at 4*s.* 9*d.* per ton. Stone for walls cost about 5*s.* 9*d.* per ton, and rubble about 3*s.* per ton. For the granite ashlar from Cornwall he paid about 2*s.* 6*d.* per cubic foot, and the granite from the Dock Board's Scotch quarries was delivered on the quay at Liverpool at a cost of about 2*s.* per cubic foot. The granite rubble, large and small, which was employed in facework of walls, however, cost about 8*s.* per ton, equal to about 7½*d.* per cubic foot. The mortar was of blue lias lime from the Halkin mountains in Flintshire, and was delivered in lumps about the size of cocoa-nuts on the quays close to the mortar mills, where it was burnt and ground. The mortar used varied according to the position in which it was to be employed. The best quality consisted of 4 parts of lime, 3 parts of sand, and 1 part of smithy ash ground together for forty minutes, and it cost about 11*s.* per cubic yard. He had learned mortar-making from Mr. James Meadows Rendel, Past President, who set great store on mortar-making, and gave him his first lessons in it. He had also followed in the footsteps of Mr. Jesse Hartley, who justly prided himself on his mortar. The cost of masonry in the ordinary run of dock walls was about 18*s.* to 20*s.* per cubic yard, and about the entrances 25*s.* to 27*s.*, including the cost of hollow quoins, sills and such like specially dressed work. The Portland cement was obtained from the London district, and at the present time cost about 39*s.* per ton; but during the construction of the works described the general price was much higher. He used neat cement for pointing; the composition of the concrete was generally 8 portions of gravel to 1 portion of cement. The gravel was obtained from different points of the Welsh and Lancashire coasts and from the Isle of Man. With regard to the criticism of the section of the retaining-walls, he could not endorse the principle which Mr. Kinipple seemed to lay down, that the depth of directors' pockets should determine the section of retaining-wall to be adopted. He preferred to rely on his own judgment and experience in such matters, feeling certain that the ultimate result would be more economical. The section of the Hornby Dock wall, though its base was wide, was certainly on the light side, being about 56 superficial yards for a wall having a clear height of 37 feet. He therefore thought Mr.

Vernon-Harcourt had taken the correct view in contending that this wall could not be regarded as of excessive section under any circumstances whatever. As the class of filling most desirable was not forthcoming for most of these walls, and as they had generally to be backed up very rapidly, they were necessarily constructed of a somewhat heavy section, in addition to which they were all designed to carry a heavy surcharge, or quay load, the necessity for which was evident. To show that an undue factor of safety was not employed: in one instance, where the backing up was very rapidly carried on, the wall showed signs of failure, but by prompt measures the movement was checked. In this matter of dock walls, he had not been entirely without that education which arose from a study of failures. The strong boulder-clay, found on the site of the Liverpool Docks, formed an excellent foundation, greatly superior, in fact, to London clay, which no doubt Mr. Vernon-Harcourt had in mind when referring to the question of foundations. The system of sluicing adopted was an important feature of the works, and involved very anxious consideration on his part. The Birkenhead Docks entrances, as designed by the late Mr. John B. Hartley, had outer sills laid at the level of 12 feet below the dock sill, or 2 feet below the lowest low-water. Unfortunately Mr. Hartley's health broke down, and he was not able to carry the works out, so that it devolved on Mr. Lyster to complete them. In carrying out the works he perceived the great value of deep sills and also of sluicing. He did not quite accord with the tradition existing in Liverpool that deep sills could not be constructed on the Liverpool side of the water. On going to Parliament, in 1873, for the large dock scheme, he was asked at what depth he thought of putting the sills. He had thought of 9 feet, but in the meantime had tried several experiments and decided upon 12 feet. He said to his Board, "If we go to 12 feet we must have works of a character that will ensure the depths of those sills and platforms and approaches being maintained." The result was the large system of sluicing. He thought that without that system of sluicing the north works could not have been maintained. He was aware that there were rivers in England more highly charged with silt and sand than the Mersey; but there was no doubt that that river carried an immense amount of matter in suspension at all times, and more especially when there was a gale of wind, or a heavy flood from up country; and wherever there was a quiet place it let its load of silt and sand drop. Whether the open basins were right or wrong, the water deposited the silt on the floor of the basins and docks. Mr. Lyster.

Mr. Lyster. That presented itself to him as a matter of great danger. The ships entering the docks were of enormous size, ranging up to 10,000 tons, nearly 600 feet long, over 60 feet beam, and drawing 24, 25, or 26 feet of water. It was important that they should get into dock, because anchoring in the river meant discharging cargo at a considerable loss. They ran, he would not say risks, but narrow shaves; they did not hesitate to enter a dock with a few inches of water under them. As a rule he kept the platforms, entrances and approaches to the sills, in the fairway 2 feet below the level of the sill. The sand and silt would accumulate in a night after a heavy gale of wind to a depth of several inches, and if a vessel came in with but little water beneath it might be a matter of very great danger. He had known vessels, worth with their cargo perhaps half a million sterling, come in with 8 inches between their keels and the sill. He did not think it right to jeopardize such valuable property; but desired to be absolutely certain that the platforms and sills were clear. He therefore swept the floors, as a room should be swept, every morning, by letting a certain volume of water out, and any little accumulation of silt could be turned back into the river by opening the sluices. He was aware that the cost of the sluices was considerable, but he could not now separate that item from the cost of the remainder of the work. He thought dredging would be a source of serious danger. He was aware that in the Tilbury Docks a vessel moved round the basin and stirred up the mud, and that the effluent current took it back into the river. That was excellent; but he was inclined to think it would not suit the circumstances at Liverpool. He should never rest satisfied if he had that operation going on, fearing that vessels might be caught and might take ground on the sills or in the basin. The Dock Board once had experience of that kind, and had to pay £70,000 for the loss of a vessel that had stuck in the lock from an accumulation of silt. That was before his day, but it taught him to make quite sure to provide proper sluices for the work to be done. The Langton Dock and the entrances were opened in 1881, and they had been in operation ever since. He had an examination made periodically by an expert diver, who walked over the bottom of the basin every spring-tide, and reported as to whether any of the concrete had been disturbed, or the caps of the up-cast nozzles moved; so far everything had been reported as in perfect order and working admirably. No one valued dredging more than he did in its proper place; but he could not admit that dredging in a basin leading to the fairway of a dock was proper. For what was dredging? It was the removal of something out of place—a sandy encumbrance. Mr. Lyster. Dredging was unsuitable for the removal of a deposit of a few inches depth only; the dredger must penetrate 2 or 3 feet, and if a depth of 2 or 3 feet of sand were allowed to accumulate for the dredger, vessels would run great risks of being caught in the entrances and breaking their backs. That was one of his reasons for facing the expenditure incurred in going to a depth of 12 feet. He might mention as an open secret that the Dock Board was now considering the propriety of providing much deeper sills, in the reconstruction of some of the old docks in other positions on the Liverpool side of the estate. Plans were before the Board for that purpose. It was very objectionable that any vessel should ever be compelled to discharge goods in the river; and it was his duty to endeavour, as far as possible, to assist the Board in providing deep-water dock accommodation, and he was at present considering the subject. Whether sills deep enough to allow of vessels drawing, say 26 feet, entering on all tides would be decided on time would show. He concurred with Mr. Duckham that it was desirable to have dock sills so low that a vessel drawing at least 26 feet of water might enter on any tide. The question of providing and maintaining that depth in some situations was a most important one, and in none perhaps more so than in the case of the Mersey Docks, where the range of tide was very great. To accommodate many vessels now in existence, the floor of an entrance should be practically level in cross section if full advantage was to be taken of its depth in the centre. For the vessels of the present day, the effective depth of entrance of many of the older Liverpool Docks was much less than their nominal depth, owing to the great rise in the haunches of the sill inverts. The forms and proportions of vessels had varied very much from time to time, and of late years the tendency in the design of great Atlantic steamers had been to increase both their length and width; so that it appeared necessary for the dock designer to allow large margins in width in designing new entrances, and to allow plenty of room in the docks themselves. The tonnage which he had quoted as having been worked through the Langton entrances in two hours twenty minutes was that passed through both entrances between Langton Dock and the Canada Basin. The latter basin, it would be seen, served four other entrances, and the opening from the basin into the river was about 400 feet wide. About the year 1879 one of the many minor changes of the Pluckington Bank resulted in its extending itself so far to the northward as to endanger the great landing stage. It came under the stage for a

Mr. Lyster. considerable distance, the consequence being that the pontoons on which the deck of the stage rested took the ground. They were not much more than boxes of iron, and several of them were crushed at various times, so that the condition of the stage caused great anxiety. He had then to consider how best to deal with the matter. Many proposals were made, and one of them was in the direction of shifting the stage further northward. He was opposed to this, inasmuch as shifting it further northward would have interfered with the entrance into the Prince's half-tide dock, and have prevented it from being fully used. What struck him was that as the tail of the bank projected under the stage, the best thing would be to cut it off by sluicing, and he accordingly constructed a series of large sluices behind the stage. He made the George's Dock, the Canning, and the other docks to the southward, the reservoirs for the water, and he put in a system of pipes along the foreshore in front of the river wall, namely, between it and the stage. The valves were lifted at low-water when the working of the docks would allow of it. They ejected a vast volume of water, cutting off the tail effectually, so that there had been no trouble since they had been set to work.[1] As they were limited to about 400 feet in length, parallel to the river wall, the tail sometimes made its appearance further northward; but as long as the interval between it and the main body of the bank was kept clear, it did not cause much apprehension. With reference to the roof cranes, he thanked Mr. Hayter for his remarks on behalf of Mr. Lyster, Jun., who was the designer. In 1878–9, when the question of bringing grain in bulk to England became prominent, one of the points he had to consider was to deal with the grain brought as part cargo. Large ships came in with perhaps a few hundred tons of grain amongst other cargo, for the discharge of which it was not convenient that the ship should leave an ordinary berth and proceed to a special grain warehouse dock, and the difficulty was how to get rid of the grain. He thought the best thing would be to have American elevators to clear it over the side into barges, and then take it to another elevator on shore to raise and send it into the grain depots. The question was where to put the elevators, that they might be ready for use when required; and his son, Mr. A. G. Lyster, thought that the roof of the shed would be a convenient place, so that they could travel along the length of the shed and be lowered into any hatchway along the range, and effect the work of discharge over the side into a barge;

[1] Minutes of Proceedings, Inst. C.E., vol. xc. p. 308.

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when that was done the elevators could be lifted up and replaced upon the roof out of the way. As, however, the shipowners were required to find such trade appliances at their own cost, the matter remained in abeyance, and floating elevators were introduced; but the roof crane, which, with the elevator, formed part of his son's invention and patent, came to the front. Referring to Mr. Kinipple's claim that he had designed precisely similar cranes; from the information he had collected in the matter, he concluded that no cranes of the special type referred to in the Paper had been constructed and brought into use by any one but himself. The crane which Mr. Kinipple described as being very similar, and having one leg on the coping and the other on the upper platform, was quite different to those in use at Liverpool, which were wholly on the roof, and this without alteration to the shed structure, except a slight additional strutting of the ridge-tree. Mr. Kinipple had evidently thought out a certain form of roof crane, and even designed one some years ago, but Mr. Lyster, under the circumstances explained, respectfully declined to acknowledge any claim for priority of invention or for bringing them into use. Mr. A. G. Lyster's crane was entirely on the roof, the slope of which it followed, giving no trouble. It was quite snug and entirely out of the way, but ready for use when wanted close to the ship, the sheds at Liverpool only being a few feet from the dock coping. The sheds were kept close to the edge of the quay on the theory of getting goods out of the ship into them as soon as possible. He had stated the amount of work that the cranes were capable of doing, and in his judgment they were admirable accessories to working a dock system economically and expeditiously. As regarded the general arrangement of the Liverpool Docks, on the foreshore of the Mersey land could not always be had exactly in the form best suited for docks for the largest class of vessels; but where the situation permitted, he thought that for the great ocean steamers, and for the trade as carried on in Liverpool, the Alexandra type of dock was the best, the body and branches being both of sufficient width to allow of the proper handling of vessels. This form gave the maximum berthage with a working minimum of water area. This led him to the subject of quay arrangements, a most important point, in connection with which was the question of railway accommodation. The trade of Liverpool was different from that of most other ports, inasmuch as it was not merely a terminus to one or more railway systems or water-ways; but it was a warehouse port, where goods imported must as a rule lie until a customer was

Mr. Lyster. found for them, and until it suited him to remove them for consumption. In the ordinary course of trade, therefore, goods had to be warehoused in Liverpool. Some were stored in the warehouses of the Dock Board adjoining the docks, others in the warehouses of the railway companies at their several receiving stations, and the greater portion in the warehouses owned by private individuals in the town; but he was not in a position to give the relative proportions of these several classes. Evidently, for the first and last-named classes, railways alongside the quay were of no benefit, and could not be used. For the goods intended to be warehoused by the railway companies, railway lines, it would be thought, must be of service. Against their use, however, had to be set the fact that most cargoes were made up of comparatively small parcels consigned to a great number of different people. Under these circumstances it was impossible to convert the dock wharf into a railway station; for in that case there would be four or five railway companies, with varying interests, all trying to get their wagons loaded, and their trains marshalled, which, without taking into account the lorries, carts and vans, could not be done on the limited quay space at command. It thus appeared that the best way to deal with mixed imports was to get them out of the ship, as quickly as possible, on to a roomy quay where they could be sorted, and where a cart could come alongside and remove them to their several immediate destinations. The only cases, therefore, in which railways could be usefully laid on the quays for import cargoes would be where ships of the "ocean tramp" class brought whole cargoes consigned to a few individuals. If there were a sufficient number of such cargoes destined for railway companies' warehouses or the country direct, it might perhaps be worth while to set aside one dock especially for that class of cargo, and lay out its quays suitably with rails. For outward goods, railway lines might be of service; but, here again, cargo steamers stayed so short a time in port, that the collecting of a cargo must be carried out in a very short time, and it must be brought to the quays while the ship was discharging. Thus, bearing in mind that several railway companies contributed their quota of cargo, great confusion would certainly result if railway trains were to bring down their cargo to the ship-side. Another factor, telling in favour of cartage, was that the quays and the streets of the town in their vicinity were very uniform in level, and the paving was generally excellent, so that the traction of road vehicles was so light as to compare favourably with rail traction. The only point in favour of railway loading would be the saving of one handling of the goods, against which there would certainly be drawbacks in getting alongside the goods, putting them on to the wagons, marshalling trains, &c., under the conditions indicated. In setting forward these explanations, he must not be understood as being in any way against bringing the railway as close to the ship as possible, or indeed as being responsible in any degree for the apparent lack of railway accommodation at the Liverpool Docks to which Mr. Giles had referred. The question of rails or no rails had prominently and unceasingly been before him for the twenty-nine years during which he had been Engineer to the Mersey Docks Estate. At the present moment there were 27 miles of railways along and through the docks and quays at Liverpool, laid down at a cost of not less than £70,000. Some of them, namely, the main lines, which ran fore and aft the estate, and joined up with the several (ten in all) railway goods stations abutting on the eastern margin of the docks, were freely and constantly used for the interchange of traffic from stations to the railway receiving depots. The remainder, about one-half of the whole quantity, were siding lines, which had been carried alongside some of the most prominent docks, and along the roadways and between the sheds. These, though laid at great cost for the purposes of carrying goods to and from station to ship, were in most cases absolutely never used. In some instances, in the most recently-built docks, he had been obliged to take up long lengths of railway which had been laid and never traversed by a single wagon, and he was now contemplating removing many hundreds of yards of track which had been laid about twenty years, and had never been used. He had joined in repeated conferences with railway directors, engineers, and managers, with the same results, that they never could see their way to use the lines; and he was informed by their traffic managers that it was more convenient and cheaper, under the special conditions of the trade of Liverpool, to transfer goods by lorry from station to ship-side, or from ship-side to station, than to marshal trains or move about isolated wagons for the purpose. The present method of working, though open to superficial criticism, might be regarded as having grown up under the special countenance of the railway companies themselves. If anything like a workable railway system, meeting the requirements and approval of the several parties concerned in the transfer of goods to their several destinations, were agreed upon, he should endeavour to give effect to their wishes. As Mr. Giles had pointed out, it was essential, if steamers of great value were to be worked profitably, that their stay in port should be as short as possible, and therefore cargo had to be discharged rapidly. From

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Mr. Lyster. this point of view there was no question that discharge into a roomy shed could be effected far more rapidly, and with less risk of damage from weather, than into wagons, however well the lines of railway might be arranged. This was a question of traffic management, well worth the attention of dock engineers. To bear his view out, he had the authority of a traffic manager of one of the most important and recently-constructed docks in London, for saying that, in the case of that dock, the existence of railway lines in front of the sheds was a mistake, and that expense in land, as well as time and labour in working, would have been saved had the shed been brought as near as possible to the ship. He hoped, therefore, that the want of railways at Liverpool would not be considered inconsistent with the ideas of the present day, but rather that the arrangement of the quays would be taken to be the outcome of the special conditions of the trade of the port, which were entirely different from those obtaining at some other places, such as Southampton and Garston, which had been mentioned in this connection. In those docks at Liverpool and Birkenhead, where the conditions were suitable, such as the coal wharves, special rails and appliances were provided and freely used. The cost of zinc roofing, taking into account the lighter framing and boarding which could be used with it, was below that of slates. It was not, however, for this reason that he for the time adopted zinc for roofs. He should have preferred the older and well-tried material, even at somewhat greater cost; but when the great sheds of the northern extension were being constructed, there was no hope of being able to obtain suitable slates in sufficient quantity in the required time, and so, after full inquiries, zinc was adopted. It had, however, in places, been subject to rapid deterioration, particularly in sheds where boilers were used for steam-winches, and as it was no longer imperatively necessary to use it, he had reverted to slates as roof covering. The floors of the double-story sheds were designed to take a load of 30 cwt. on each square yard; these buildings ought not to be looked upon as warehouses in which goods were stored, but merely as sheds in which they remained for a short time till they could be sorted and sent off by road or rail to their destination. With regard to the revenue per ton of shipping at London and Liverpool, the figures in the Paper did not include any items for handling goods, which at Liverpool, except in the case of one or two enclosed docks, was not done by the Board. With respect to the claim that the honour of constructing the first tidal wet-dock belonging to London, and not to Liverpool, he could only say that although he never attempted to

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look up all information on the subject for himself, he had very good authority for his statement that the Liverpool Old Dock was the first tidal wet-dock constructed in England. Some years ago he had corresponded on the subject with the late Sir James Picton, well known as the historian of Liverpool, who then went into the matter very fully. Mr. Lyster would not then recite all the evidence brought forward, in which the claims of the Howland Great Wet-Dock, amongst others, were dealt with, but might quote the concluding paragraph of a report on his investigations, which ran thus: "I consider that the claim of Liverpool to the origination of the first public floating dock stands unimpeached." He wished to avoid re-opening the prolonged and complex discussion on the question of the effect of the low-water channel upon the condition of the upper estuary, which had been fully investigated during the consideration of the Manchester Ship-Canal Bill by successive Parliamentary Committees. The theory of the wandering of the channel, being the remedial measure that nature had adopted for maintaining the capacity of the estuary, appeared to him to be then incontestably proved, and nothing he had since heard had changed that opinion. No doubt the body of water in the Crosby Channel, outside the Rock Lighthouse, also played a most important part in maintaining the sea channels across the banks; but he need scarcely point out that the Crosby Channel itself had to be maintained, and he failed to see how its maintenance would be secured if there were no upper estuary to act as a reservoir for sluicing water. He had listened with great interest to the remarks of several speakers on the subject of the bar of the River Mersey. All were agreed that the bar constituted a very serious obstruction to the trade of the port, and he did not wish to question the fact; but at the same time he would like to point out that there were circumstances in the case which prevented the obstruction being intolerable. For several hours in each twelve there was water over the bar for vessels of the deepest draught, and even if vessels could cross the bar at any state of the tide, they could not enter the docks except at or near high-water. The chief legitimate causes of complaint, therefore, were that the detention to inward-bound vessels outside the bar somewhat imperilled their safety, and, in the case of slow vessels, might cause them to miss their chance of docking. The most weighty grievance was the detention of passengers on board the great liners, and the inconvenience caused to them through having to be transferred to tenders instead of proceeding to a stage to disembark. The Mersey Docks and Harbour Board was fully aware of the neces-

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Mr. Lyster. sities of the case, and of the force of the calls made for improvement, and was also, perhaps, better able than many others to appreciate the physical and financial difficulties to which he had referred as surrounding the question. At present, as would be understood, he was not in a position to discuss fully and freely the several interesting points as to training-walls and other such remedial expedients, and he would have merely to say that the Board had quite recently decided to try an experiment in dredging, no doubt in some degree moved thereto by the fact that a measure of success had attended certain dredging operations in New York, with which port the shipping interests of Liverpool had a close connection. Personally, he was not to be considered as of opinion that the sand-pumping experiment would approach the results which some people expected from it; but it would give an amount of experience which would be interesting, and not without its uses in connection with the study of the general question of the amelioration of the sea channels of the Mersey. He could not now speak as to what works ought ultimately to be undertaken, nor as to the manner in which the cost of those works should be defrayed.

Correspondence.

Mr. Carr. Mr. R. Carr enquired the cost of the sluicing appliances laid down at the Canada Basin, so that it might be compared with that of other systems of keeping dock-entrances clear from sand or mud silting. In addition to first outlay, what was the cost of maintenance, and was there any special cost for labour whilst sluicing? It might be that this was done by the men employed in locking vessels, in and out, as part of their ordinary daily duty. And what was the effect within the Langton Dock, which was drawn down about two hours every tide, with the double purpose of sluicing the entrance and meeting the rising tide, to make a level? Did the volume of flood-water, brought in by the tide, leave a deposit of silt that had to be taken out; if so, what cost did it involve, and how was the silt removed? At the Tilbury Docks on the Thames, there was a tidal basin, bearing a close resemblance to the Canada Basin, with a wide entrance, open to the tide at all times. It was 19 acres in area, and, when first opened, it cost a large sum annually to maintain a depth of 26 feet below low-water level by the bucket-ladder system of dredging, and depositing the mud on the land. At present it was kept clear to that depth by an invention of Mr. Tydeman, one of the West India Dock staff.