point. Mr. Meik had referred to the large expenditure which had been incurred at Rangoon on plant. A long experience of work in the tropics had convinced him that plant which was laid up after the completion of work deteriorated far more quickly than when it was usefully employed. In view of the deterioration of such plant as was now available for carrying out work of a similar class, it was to be hoped, in the interests of Rangoon, that not much time would be allowed to elapse before the further works, which were urgently required and which he was quite sure could be taken in hand with similar favourable results to those described in the Paper, were proceeded with. Sir William Matthews.

*** As to the Author's reply to the Discussion, see p. 239.—Sec. Inst. C.E.

Correspondence.

Mr. L. M. Bell considered that it would be interesting to know whether there was any evidence that the mattresses still existed. If possible, jungle brushwood such as the mattresses were made of might be useful for other engineering work in the tropics. It was well known that in the tropics most brushwood, and immature wood generally, was soon attacked by insects on land and reduced to powder. In the sea also destruction appeared to be fairly rapid, though evidence of this was difficult to collect. Mangrove and bakau wood seemed to resist the attacks of sea-worms fairly well, though even they generally gave way near the sea-bed level after 2 or 3 years. If constructed of mangrove brushwood and well covered with stones and sand the mattresses might however last a considerable time. At all events, at Rangoon the mattresses seemed to have served the immediate purpose in checking scour. In cross section No. 3, Fig. 14, Plate 5, the bed of the river was scoured to about 66 feet below the apron at a distance of about 140 feet from the edge of the apron, so that in cross section the slope of the river bed was nearly 2 to 1. With a bed composed mainly of sand exposed to strong tidal currents this did not seem to be safe, and probably further protection was necessary. Tipping rubble on the slope might give the necessary protection. Any further information that could be given as to the behaviour of the mattresses and apron where affected by the tidal scour would be of value. It would appear that it might have been possible to reduce Mr. Bell.

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Mr. Bell. the length of this long and expensive curved wall. The conditions appeared to indicate a straight wall starting from the river-bank about 3,000 feet south of the small jetty shown at the Seikgye staff-quarters, and extending thence in an east-south-easterly direction, heading for Mower's Point, and about 3,000 or 3,500 feet in length. Such a wall would have deflected the current fairly down the straight of the river in front of the wharves, without, it is thought, endangering the wharf-foundations. It would have had the additional advantage of further deepening the river in front of the power-station, etc., towards the northern bank, and would probably have removed the Ahlon shoal more effectively than the curved wall had done. The momentum and centrifugal force of the ebb-tides would have been very little greater than with the present curved wall, as the water would have cushioned itself. It was true that navigation of the corner might have been a little more difficult; but to the small river-steamers which went above Rangoon this would make little difference. No doubt the Author had given the matter consideration, and it would be instructive to have his reasons for the more expensive undertaking. The long curved wall carried so far back seemed to be responsible to some extent for the back current on the ebb-tide, which in its turn was probably largely responsible for the Ahlon shoal. Although a contractor possessing the necessary plant might have been able to carry out the work more cheaply, yet, having regard to possible or probable modification in the work, there could be no doubt that the freer hand given to the engineer by departmental work had been justified. The opening up of the special quarry had given the necessary control of the market, otherwise the railway stone would probably have cost more, and it was doubtful if native contractors could have been depended on to maintain the supply alone. The Author was to be congratulated on carrying so difficult a piece of work to a successful conclusion.

Sir John Benton. Sir JOHN BENTON cordially congratulated the Author on the execution of a great work, which very effectually removed a long-standing menace to the safety of Rangoon Port. When Chief Engineer, Public Works Department, and *ex-officio* Chairman of the Port Commissioners, in 1900 and the first part of 1901, before the arrival of the Author, he came to the conclusion that the removal of Mower's Point, as previously proposed, was a remedy likely to result in shoaling in front of the left-bank wharves, and that the only complete remedial measure was the drastic one of constructing a great training-work to start about the upper end of the right-bank embayment on the right bank, and to terminate a short distance above Mower's Point. Having

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been a member of a Committee which proposed removal of Mower's Point, he officially retracted that recommendation, as far as he was concerned; it was considered inexpedient to advance proposals with regard to the training-works, because during his predecessor's tenure of office the Secretary of State had been asked to nominate a whole-time Chairman and Chief Engineer for the Port Commissioners, and it appeared desirable that this officer should start untrammelled by any partially-developed proposals. He was asked by the Author, shortly after the latter received charge in 1901, to accompany him over the river. The river menaces were discussed, and in conclusion he was asked by the Author what remedial measure he would have advanced if he had continued in charge; the reply was a river-training work as described above. As far as he was aware, this was the first occasion on which it was proposed by anyone to construct training-works, and he was glad to find subsequently that the Author's mature consideration had led him to the same conclusion. Regarding the alignment proposed by the Committee of 1906, he recollected the late Mr. J. R. Bell drawing on the surveys with his own hand the line which was then accepted; it was one which just admitted of Mower's Point being cleared on the north side, while *Fig. 6* (p. 153) appeared to indicate a line a good deal farther north than would be required for the attainment of the object just mentioned. However this might be, the important question was whether the adopted alignment was the best that could have been selected. With all due deference to the Author there appeared to be some grounds for doubt on this subject. It was stated that the ebb- and flood-tides were nearly parallel opposite Mower's Point, rendering dredging on the left side unnecessary, except at long intervals; that the removal of Mower's Point was estimated to cost £70,000; and that its execution promised to improve the inner harbour, but to increase the amount of dredging needed on the left-bank wharves. Tidal lines of flow were not shown. The centrifugal force of the ebb-tide promised to result in the deep stream hugging the right bank, and the configuration of the ebb-tide and flood-tide approach-channels afforded little assurance of parallelism of the flow. The Author's admission that, whatever was done about the removal of Mower's Point, some dredging would always be required on the left side, did not amount to a demonstration that the alignment of the Committee of 1906, if adopted, would have caused dangerous scour; on the contrary, the alignment of the Committee might have avoided the admitted defects of the Author's executed work. There was nothing in common between the temporary brushwood-mattress Sir John Benton.

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Sir John Benton. design of the Author and the late Mr. P. W. Meik and the very substantial permanent work of the Committee of 1906, which superseded the former. The Author stated that the former was thought to be too complicated, and that it met with severe criticism; this description appeared to be incomplete. The design consisted of a series of bamboo and brushwood mattresses loaded with stone, from river-bed to low-water level, and with a pitched slope thence to 5 feet above H.W.O.S.T. There were offsets on the face and rear of the work between the different layers, which had to be laid, in great depths of rapid turbid tidal flow, with a higher degree of accuracy than promised to be attainable, while any incorrectly laid mattress could not be moved. There was a far more serious objection, namely, the certainty of early destruction by the teredo before the river could possibly be diverted, while the training-works would be required to endure for many years. It was recorded in the Paper that the teredo destroyed the dolphins, alongside the training-works, in 4 to 8 months; and it appeared quite certain they would have destroyed the training-works also if the design of the Author and the late Mr. P. W. Meik had escaped the severe criticism which led to its rejection, and if an attempt had been made to carry it out. The foundation mattress had never been found necessary in the case of any of the great weirs and under-sluices constructed for irrigation-works on Indian rivers with sandy beds, and discharging up to 700,000 cubic feet per second, nor had it ever been used for railway-bridge works. The maximum velocity and violence of action in these rivers exceeded what had to be resisted on the Rangoon river—as regards side and end scour. The weirs and undersluices of canal head-works depended on the rubble-stone aprons sinking evenly to the usual 2-to-1 slope and to the maximum depth of scour, when laid horizontally on sandy or alluvial formations; the sinking had been more regular than indicated in the section given in the Paper, and there had never been any failures. He had always attributed the Author's predilection for the unusual addition of a mattress to lack of experience of what was feasible with rubble stone alone. The Author's labours, and those of his staff, would, in Sir John Benton's opinion, have been greatly reduced by omitting foundation mattresses, which had apparently cost no less than £111,436, and the saving of this amount was very desirable. The expenditure of any such sum as £140,000 on the steel gantry was recognized as unwarrantable; it was also recognized that the gantry would have been a very serious obstacle to the barges bringing stone. The proposal to have a gantry had been advanced mainly with the object of facilitating control of the $22\frac{1}{4}$ feet of tidal flow, and to hasten the completion

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of reclamation; these objects had not been very fully provided for by the executed design, which still left an average depth of about 11 feet of silt to be laid down throughout the 300 acres of reclaimed embayment. Nevertheless, he was of opinion that the braced reinforced-concrete slab boxes, filled with rubble stone, were an excellent device for the superstructure, since they acted by gravity, and required no anchorages. If these concrete boxes had commenced at a level low enough to admit of their being carried up to H.W.O.S.T. (108·9 feet, or 4·9 feet higher than built), the crest-width would have sufficed to admit of this amount of raising, and control would have been complete. There would have been no difficulties, as far as could be seen, in commencing at a lower level. Providing for the removal of Mower's Point—if to be carried out—and completion of reclamation, were integral parts of the scheme, and, in his opinion, should have been treated accordingly. Sir John Benton.

Mr. HAROLD BERRIDGE remarked that the two main questions presented by the Paper were whether the solution adopted was the best, and whether it had been carried out economically. The first question appeared to have been thrashed out in great detail. It seemed to him, however, extremely unsatisfactory that the work should have been delayed so long by differences of opinion on constructive details; and assuming urgency of the work, the danger apprehended must have increased considerably during the delay. Engineers often felt touchy about their pet designs, but there were generally two ways of effecting a desired result: if superior authority approved or demanded designs or methods with which an engineer felt himself unable to agree, that authority could take the responsibility, the engineer recording his opinion or protest before starting the work. The Author had not adduced very prominently his reasons for providing the mattresses as an integral part of the design. Doubtless they prevented settlement and scour, but the bottom did not seem very bad; in the light of experience, did the Author still think them indispensable, or would the stone bank have found its own bottom? The cost of the mattresses had been 1*s.* per square foot, or £112,000, equal to the cost of 224,000 cubic yards of stone at 10*s.* Taking the foundation area as $224 \times 42 \times 27 = 227,000$ square yards, this would have allowed practically 1 yard of vertical settlement over the whole bank. Apart from this question he would like to know the Author's view as to whether revetment of the existing river-bank by the mattress system used on the Mississippi[1] might not have answered; that Mr. Berridge.

[1] J. A. Ockerson, "The Improvement of the Lower Mississippi River." Proceedings International Engineering Congress, Glasgow, 1901, Sect. II, p. 68.

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Mr. Berridge. was to say, whether a mattress revetment in shallow water would not have answered as well as building a training-wall in deep water. Perhaps when the Author took charge it was too late to adopt this plan; but to an outsider it seemed, at all events, that if protection had been taken in hand earlier, a large part of the expenditure finally incurred might have been saved. The mattress system appeared to be that evolved on the Mississippi, adapted very successfully by the Author to the conditions at Rangoon. Anything of such dimensions afloat in a strong current was a "handful," and the manœuvring into position must have been anxious work, creditably accomplished. The method of setting out seemed to follow the usual engineering method of beacons in transit, which was no doubt very convenient where the shores adjoining were flat and close. Mr. Berridge had found, however, at Aden, where one shore was 4 miles distant and the other rose at a very steep slope, that it was much easier to use the ordinary hydrographic method of a few fixed beacons to which angles were taken by sounding quintants, and the position plotted at once by station pointer. He would be glad to have particulars of the double sextant, with which he was not familiar. As to the stone filling, the final cost of about 10*s.* per cubic yard seemed at first sight very high. Was the loading-berth for hoppers at Kalagouk sheltered? It seemed to him that a pier and side-tip wagons on a railway would have got through the loading much quicker than the 60 tons per hour stated by the Author; even if more expense had been incurred in installing the railway, the reduction of time would have been a very important consideration with such a long trip as 135 miles. Steam hoppers were very economical if kept steadily at work, but standing charges soon mounted up with slow loading. He would be interested to know if the standing charges for the hoppers agreed with the empirical formula he had devised.[1] Speaking from memory, he believed the "Pelican" was fitted with a rotary cutter on the suction-pipe when she passed through Aden on her way out; if that was the case, had the hydraulic jet been found more suitable. He would also like to know whether any studies of the pipe-friction while pumping sand had been made, and whether they agreed with Dr. Unwin's formula[2]—

$$\frac{h}{l} = \frac{m}{d^x} \cdot \frac{v^n}{2g},$$

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[1] Minutes of Proceedings Inst. C.E., vol. cc, p. 428.

[2] "A Treatise on Hydraulics." 2nd edition, p. 216. London, 1912

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for which Mr. Berridge had deduced[1] for the pipe-lines of the Mississippi dredgers the constants $x = 1 \cdot 39$, $n = 1 \cdot 87$, and $m = 0 \cdot 0425$. He appealed to the Author, in common with all engineers, to give more illuminating details as to the equipment and performance of such craft. False standards, based on incomplete records, had been set up for dredgers of all classes, and it was quite time authoritative figures were available, no less in the interests of engineers than in those of the public bodies they advised and worked for. Of course, when work was in full swing, experiments to obtain data of this sort could seldom be made, but when work was approaching completion, or in seasonal interruptions, it could be undertaken with very little trouble. Mr. Berridge.

Mr. G. WOULFE BRENAN considered that the narrative of the difficulties contended with over a period of years in arriving at an approved design was instructive, as it could not be denied that in the end it had been all to the benefit of a work of so much importance, and in which there were so many contingencies, that serious criticism was encountered, while it reflected all the more credit on the patient persistence with which the Author had adhered to and finally proved the correctness of his proposals. Moreover, this training-wall, which had been carried out in a depth hitherto unattempted, was a remarkable example of what could be done by good organization, dogged energy, and ample funds. To all who had had to deal with the training of even small rivers nothing was so discomfiting as an attempt to control flood-waters assisted by the powerful action of tidal ebb and flow. The problem was one in which the principle of give and take was always uppermost, for the forces of Nature never departed from that law. The adoption of the mattress foundation in such depths of water as existed on the site had been clearly an essential to success as well as a vast economy of material. There were many risks connected with it, as the Author showed, not the least of which was the doubtful stability of the local brushwood, and the difficulty of training the coolies to the proper method of construction, towards which, happily, their painstaking natures particularly qualified them. The cutting-off of the embayment, and restoration of the old course of the river, coupled with the silting-up of the embayment portion cut off, had involved the scouring of a deep basin on the concave side of the new wall, which had the effect of discharging, or spending the energy of the flood and ebb waters. If the curve of the wall were too sharp, and the cross-sectional area too much contracted, the Mr. Brenan.

[1] *Engineering News* (New York), vol. lxviii (1912), p. 117.

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Mr. Brenan. immense forces at work would tend to undermine the foundations of the wall and increase the current to a dangerous degree. For the same reason he considered that the shoal bank beyond the deep basin shown in the longitudinal section (Fig. 2, Plate 4) should be retained, and Mower's Point should not be removed. Both of these formed a barrier to over-scouring, acting as a sort of weir to control the current, which condition it was of the highest importance to maintain. The tidal action, vastly increased by the floods, was to scour the river-bed and thereby reduce the hydraulic gradient, so that in course of time the natural erosion of these shallows would follow by channelling, and their conservation might become necessary to some extent. The accretion in the embayment behind the training-wall would, as it grew in height, increase the ebb-current in the river very materially, and assist the scouring action of the waters below Mower's Point. He thought this was a matter that would require watching. On the other hand it might be argued that the removal of part of the Point would tend to diminish the current by enlarging the waterway. In his view, however, the tendency to erosion still remained on that side of the river, and it should not be assisted by any removal of the river-bank in that locality. The Author's views in this direction were well founded.

Mr. W. Dyce Cay considered that, looking at the works in the interests of the port of Rangoon, it would have been better if the whirlpool of the bend had been removed farther up the river, and the latter had been given as far as possible a straight channel past the town. For this object the work would have been begun about 1 mile higher up, with a bend into the right bank, followed by a sweep to the left into a straight reach containing the harbour. The River Dee at Aberdeen had a long straight channel below the curve by which it was led from the old course, and it was suitable for basins and wharves.[1] He thought there would be silting at the Rangoon wharves, and a little of it was shown on cross section No. 4 (Fig. 13, Plate 5). He had had an opportunity of seeing, along with a Congress excursion party, the construction, in progress, of the works of Hollandsch Diep, on the 31st July, 1894. Large deep holes in the river-bed were being filled with dredged sand, covered with willow mattresses loaded with rubble. The typical size of the mattresses was 65 feet broad by 195 feet long by 17 inches thick, with three layers of fascines; the cost of them in

[1] Minutes of Proceedings Inst. C.E., vol. cxxxi, p. 79, and Admiralty chart of Aberdeen.

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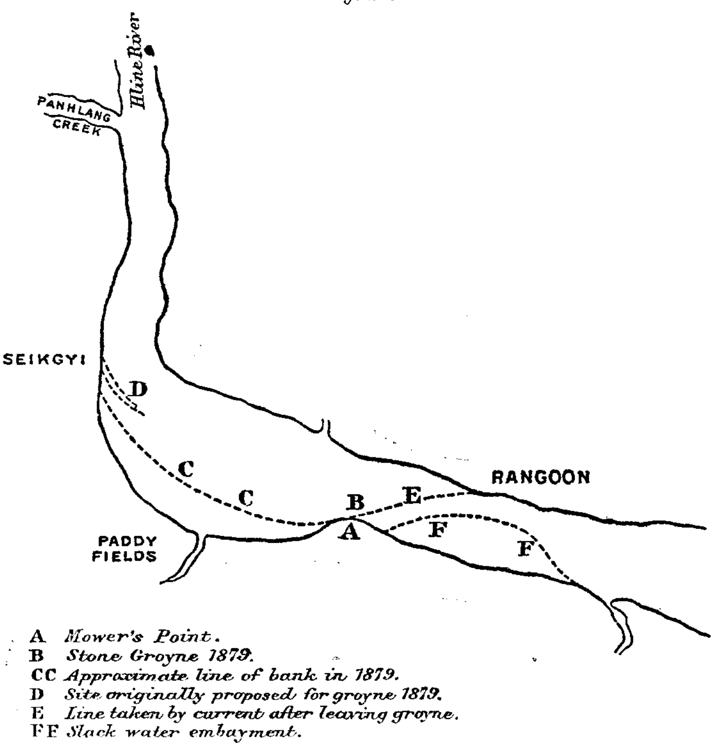
place was equivalent to about £1 1*s.* 8*d.* per 100 square feet of area. Mr Dyce Cay.
The current on completion was $6\frac{1}{2}$ feet per second.

Mr. D. D. Coath stated that his experience of the Rangoon Mr. Coath.
river went much farther back than the Author's. In 1878 erosion above Mower's Point first attracted serious attention because it endangered a brick-built rice-mill which had just been completed near that point. The erosion had been greatly accentuated by

Fig. 21.



the abnormal freshets during the monsoon of that year; and so great was the flow that for fully 4 months ships in the harbour did not once swing to the flood-tide. At that time, and until about 6 or 7 years later, the Panhlaing Creek was a large deep navigable river used regularly by the largest river-steamers, which thereby saved about $1\frac{1}{2}$ day's steaming on the voyage to Mandalay. It was then estimated to bring down one-third to one-half of the whole flow of the Rangoon river. About 1885, through obstructions such

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Mr. Coath. as trees being allowed to accumulate at various points, the Panhlaing Creek began to silt up, and from that time forward it became less and less navigable. Early in 1879 he was called on to advise the owners of the mill at Mower's Point as to the best means of saving the mill, and, as it was quite clear that any protective works should be placed much higher up, he suggested a stone groyne at the point shown in *Fig. 21*. Nearly all the land between Mower's Mill and this point was vacant waste land of no particular value, belonging to Government, but all Government assistance in the matter was refused. Under the circumstances he advised the owners of the mill that the next best thing would be to construct a groyne or spur of rubble at the extreme upper limit of their land, which was done, a groyne running out obliquely, as shown in *Fig. 21*, being constructed by dumping rubble stone by hand from barges. No funds for anything elaborate being available, what was aimed at was the formation of a groyne about 10 feet to 15 feet above the natural bank; no particular trouble was experienced from washing away of the stone till near the end, when a good deal was lost; but this difficulty was completely overcome by sinking the hull of a small condemned ship partly filled with sand. The groyne cost less than £3,000 and was perfectly successful, and for 30 years, during which not a penny was spent on its maintenance, it steadily deflected the whole rush of the river obliquely across to the Rangoon side, where, in a few years, it began to play havoc, cutting away large slices of the foreshore, together with several landing-stages. At about three-quarter ebb there was always a sharply defined line between the deflected current and the stretch of comparatively quiet water commencing immediately below the groyne—so sharp, indeed, that a 50-foot launch steering across it would be swung round about 40 degrees or more. If this groyne had been constructed on the site originally suggested, instead of deflecting the current across it would have directed it straight down the middle of the harbour, and would thus have accomplished all that had since been attained by the elaborate and very costly works described in the Paper. A dozen, at least, of similar groynes could be seen on the Nile between Cairo and Assiout at points where the current required deflecting from the bank. With this object-lesson of what had been done by inexpensive means, he had always been puzzled to understand what process of reasoning had led the Author and his coadjutors to start off, as they had apparently done, with the idea that nothing short of some gigantic works would meet the case. They seemed to have entirely overlooked the important fact that once a flow of water such as that in the

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Rangoon river was deflected into a particular direction it would naturally tend to keep that direction until caused to deviate from it; and once that deflection was accomplished a shoal composed of fine sand and silt, such as the Ahlone sands, would speedily be washed away without any dredging by a current of much lower velocity than that of the Rangoon river. A current which could erode a hard clay bank at the rate of 20 to 30 feet in a week would make short work of soft silt and sand; indeed, as mentioned in the Paper, this had actually occurred, for the Author stated that a very large portion of the sandbank had been washed away through the harbour. Overlooking these two points, the Author and his coadjutors appeared to have approached the matter from the point of view that an embankment and dredging were the appropriate measures, the problem being still further complicated and its cost very much increased by the inclusion of a reclamation scheme of negative value. The difference between the method adopted at Mower's Point and that of the Author might be illustrated by regarding the river at the Seikgyi bend as a large pipe, the flow from which could be directed in the desired direction either by putting in a suitable elbow or by the more expensive plan of laying a pipe the whole way. It was difficult to understand the reasoning which had led to the adoption of mattresses; obviously they could be of no use as rafts to distribute the load on the river-bed, nor could they be of any permanent use to resist scour, because during 4 months of the year the river was infested with teredos which rapidly destroyed even the most durable woods. He once saw part of a teak ship's gangway, 3 inches thick, completely riddled, through being immersed for 9 or 10 days. As long as the brushwood of the mattress was buried in silt it was of course completely protected, but the action of the current must wash away the silt and let the teredos get to work on the parts exposed, which being eaten away, exposed more silt to be washed away in turn, allowing a fresh lot of brushwood to be exposed to the teredos, and so on indefinitely. Under these circumstances, brushwood could afford no permanent protection against the combined effect of scour and teredos. The idea seemed to have been that the mattresses outside the toe of the slope, with their covering of stone, would subside as scour proceeded, and prevent the wall from being undermined: this would be understandable if the mattresses were of sufficient transverse strength and of imperishable material, neither of which conditions was fulfilled. Looking at the top section in Fig. 7, Plate 4, it was interesting to consider what was likely to happen when the bed became scoured out to the depth shown on the lower section; it

Mr. Coath.

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Mr. Coath. was reasonable to expect that, as the sand under the outer edge became scoured out, mattress C would slide forward and down, either as a whole or in sections, leaving a large gap between its inner edge and B, with which there was no connection; B would follow the same course later, till eventually the wall itself was undermined, the rapidity of the process depending on the rate at which the brushwood became exposed and destroyed by the teredo. It was still more difficult to understand why it had been even considered necessary or desirable to construct a practically watertight embankment up to such a height. As was seen at Mower's Point, a groyne of relatively small height did all that was required, namely, broke and deflected the mischievous force of the current without entirely stopping the flow; in that case what continued to flow over the groyne was so reduced in force as to be harmless, yet enough to prevent the formation of a sandbank in the embayment below the groyne, as would have been the case if a retaining-wall, such as that described, had been constructed. The thing most difficult of all to understand, however, was what had induced the Author to include a scheme for reclaiming the bight behind the wall. This had added fully one-third to the cost, and by the time it was completed, if it ever was, it would have accounted for well over 50 per cent. of the total outlay. Great importance had been attached to the reclamation of about 300 acres of land, but apart from river-frontage, land on the right bank had no great value—probably, as paddy land, not more than 4*s.* per acre per annum. There was abundance of it, and a glance at the plans showed at once that the extent of river-frontage instead of being increased would be diminished. Further, on that side of the river land with river-frontage was not wanted for jetties or for accommodating deep-draught vessels, but for rice- and timber-mills, for which a strong current, such as swept the Author's river-wall, was a great, if not insuperable objection. The ideal site for rice- or timber-mills was a long easily-sloping foreshore on which boats and rafts could lie, with a moderate current. Again, the existing river-frontage consisted of hard clay capable of carrying safely loads up to 2 tons per square foot, whereas the reclaimed land would be composed of silt and loose sand of any depth up to 90 feet or perhaps more. He had had some experience in connection with large buildings in Rangoon, and he did not envy the task of anyone who had to erect a heavy building, such as a rice-mill with its high chimney, on such land. By the time it was finished the net result would be the creation, at a cost of nearly £20,000 an acre, of reclaimed land of

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much less value than the existing land, which, deprived of its river-frontage, would have its value reduced at once to about £5 or £6 per acre. The crying need of Rangoon was not land on the opposite bank but harbour accommodation. One of the objects of the elaborate training-works was to enable the mooring accommodation for deep-draught vessels to be extended, by deepening the water on the right bank below Mower's Point. But deep-draught vessels formed only a part of the craft using the port; there was a large and rapidly increasing fleet of large river-steamers, innumerable flats and barges, paddy boats, launches, and tugs, for whose anchorage deep water and strong currents were very undesirable. Many of these found accommodation in the embayment below Mower's Point and also below the Ahlone sands; when displaced from there by deep-draught vessels, where were they to go? What more ideal accommodation could be found than in the 300 acres of bight behind the wall which was being rendered useless for the purpose by an ill-conceived and costly reclamation scheme? When the true position was realized, there could be little doubt that some of the Author's work would have to be undone, and an opening made in the upper end of the wall to permit a flow of water sufficient to keep the 300-acre bight open. Having retired from Burma in 1903, Mr. Coath had found it difficult to follow the apparently interminable discussion over the proposed works, but in 1909, becoming aware that the project for a long wall had been decided on, he drew the attention of the Government of Burma to the novel and economical method of constructing sea-walls employed at Zeebrugge,[1] which consisted in the use of large hollow monoliths of reinforced concrete floated out and sunk in the required position, and filled with sand. He suggested that such a method of construction was eminently suitable for Rangoon, where stone was scarce and extremely expensive, whereas excellent sand was available free of expense; the cost of such a wall would have been less than one-fifth of that of the wall as carried out. Although by that time the work had been sanctioned by the Government of India, the Government of Burma was so favourably impressed by the suggestion that they forwarded it to the Commissioners of the Port for their views. The Author, doubtless wearied by the years of discussion and argument, and probably dismayed at the prospect of the whole matter being re-opened, did not favour the suggestion, which he declared to be of no practical value, and the idea was shelved. In view of subsequent events, it was unfortunate that

Mr. Coath.

[1] Minutes of Proceedings Inst. C.E., vol. cxxxvi, p. 285, and vol. cxlv, p. 317.

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Mr. Coath. the suggestion was not made earlier, for later on a modification of the Zeebrugge system was adopted by the Author with great economy and success—indeed, it was practically the only feasible means by which the wall could have been carried up to the desired height. A glance at the cross section showed at once how easily this system might have been adopted on a much larger scale, and the enormous saving that might have been made, bearing in mind that the stone had cost £1 15*s.* 8*d.* per 100 cubic feet, and that suitable sand could be had for nothing on the site. The weak point in the modified system adopted by the Author was the steel tie-rods, the failure of which must inevitably cause the collapse of that portion of the wall. The Author said these rods were protected from corrosion; it would be interesting to know by what means. The water of the Rangoon river was far more destructive than sea-water to iron and steel. He had seen $1\frac{1}{4}$-inch bolts reduced to practically nothing, and 6-inch by 3-inch by $\frac{5}{8}$-inch channel bracings eaten completely away in less than 3 years, and his experience was that nothing short of embedding in Portland cement—and not always that—afforded any permanent protection. The rods to fail first would naturally be those longest exposed to the water, namely, the lowest tier; their failure would bring down the tiers above. The Author, of course, had no concern with the river outside the Port boundaries, but it was unfortunate that there was not more collaboration between the Port Authority and the Local Government, as the whole question of river-training might have been solved, and at practically no cost to the Port. After the Panhlaing Creek ceased to be of use for navigation, about 1885, the need for some means of communication with the main Irrawaddy river became more and more urgent. A canal for small boats was made, but it was soon found inadequate, and about 1910 the Government of Burma seriously considered a project for clearing out and restoring the Panhlaing Creek; principally on account of the Author's fears of the consequences of increasing the flow of water on his works, this project was abandoned, and the construction of a large canal was mooted; and for 3 or 4 years a very active controversy had been going on regarding this matter. Some time about 1882, as a means of getting over the erosion difficulty, it was suggested by, Mr. Coath believed, the late Mr. C. H. Graham Smith, Assoc. M. Inst. C.E., to divert the Panhlaing Creek, so that instead of flowing into the Rangoon river at Kemendine it would debouch, as shown in *Fig. 22,* at an angle so designed that the two currents would neutralize each other, the resultant flow being straight down the centre of the harbour. This

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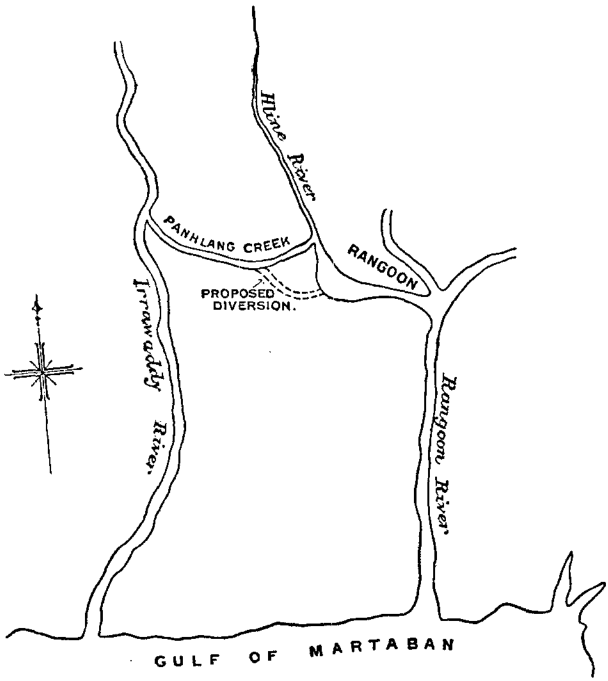
work, carried out by hand labour, was estimated to cost about £70,000, which in those days was considered far beyond the financial resources of the port. There could be no doubt that this was a perfectly feasible solution of the difficulty; it would have accomplished simultaneously three much desired objects, namely, training the river, opening up a very desirable means of communication with the main Irrawaddy, and providing numerous very valuable sites along its banks for rice-mills; moreover, the work being Mr. Coath.

Fig. 22.



a provincial one, much of the cost would have been defrayed not from Port but from Provincial funds. The result of the vast outlay on the non-productive works described in the Paper was that financially Rangoon was crippled for many years to come; its reputation as a cheap port had suffered, largely on account of the enormous increase in the dues—sixfold, Mr. Coath believed. Worst of all, practically nothing had been done to improve the approaches to the harbour, which were no better than they were 35 years ago; indeed, taking into account the increase in the size of vessels using the Port,

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Mr. Coath. the difficulties, particularly from the Hastings shoal, were much greater: how serious they were might be gathered from the fact that on his leaving Rangoon after a visit early in 1914, there appeared to him to be far more large steamers anchored below the Hastings shoal than in the harbour itself. In 1914 he had an opportunity of inspecting the completed river-wall and the means adopted for carrying it out; the skill displayed, especially in the difficult work of sinking the mattresses, reflected the greatest credit on the Author and his staff, especially as much of the work had to be carried on in a trying climate and with not very efficient labour.

Sir Otway Wheeler-Cuffe. Sir Otway Wheeler-Cuffe, Bart., asked (1) whether the fact that dumping stone from the toe of the wall to Mower's point saved the mattressed wall from being undermined, did not prove that the £111,436 spent in mattresses was unnecessary? The place where unmattressed stone was used was where the scour was greatest; if, therefore, unmattressed stone stood here, it would have stood anywhere. (2) Why had it been considered necessary to fill across the new mouth of the Kanaungto Creek, instead of leaving a channel open, as depicted in the alternative designs shown in plan on p. 153? (3) Was the Author certain that stone had not been dumped in to a level of less than 30 feet below L.W.L.? If so, how could he account for the existing depth of less than half of 30 feet at this place? (4) Had not the net result of this submerged wall been to silt up the mouth of the Kanaungto Creek from 60 feet to 3 or 4 feet, due to breaking the Kanaungto Creek tidal wave? And would it not be extremely serious if the great rice-milling centre, the Kanaungto Creek, silted up as a result of this change of design? Would the wall not have stood without adopting this drastic step? Would it not have been advisable at first to dump stone at a slope of, say, 1 in 3 from the toe and see the result, rather than kill the tidal wave with such a sudden obstruction right across the entrance? (5) Had the Chamber of Commerce, who were so interested in the rice trade—or the Public Works Department, who were improving the Twante Canal, which closely concerned the Kanaungto Creek—been consulted or warned of the obvious consequences before the stone was dumped? How did the Author propose to remedy this existing threatening calamity? Were not dredging operations in hand to keep the entrance to the Twante Canal and Kanaungto Creek open, and were they successful? (6) Had not the harbour deteriorated as regarded anchorages for large sea-going steamers since the completion of the wall, and if so, to what did the Author attribute this serious state of affairs?

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Mr. J. M. S. CULBERTSON had had the privilege, as assistant to Messrs. P. W. and C. S. Meik, of working upon the remarkably complete set of plans and records of the behaviour of the currents and range of the tide at the Port of Rangoon. It would be interesting if any statement could be given of the cost of the survey carried out preliminary to the drawing up of plans and reports. It would also be of great interest if information could be given as to the actual output of the suction dredger over a period of several months, and whether any difficulty had been found in keeping an even feed and thus avoiding choking of pipes. The Port of Karachi had a fine suction dredger ("Graham Lynn") of the non-propelling type, built by Messrs. Lobnitz and Company. She was completely erected at home, sent out in pieces, and re-erected in the Port's workshops in 9 months. The "Graham Lynn" was 220 feet long, 36 feet broad, and 15 feet moulded depth, and had a draught of 11 feet under working conditions. She was fitted with one 30-inch centrifugal pump driven at 240 revolutions per minute by triple-expansion engines of 1,600 I.HP. having a nominal capacity of 1,000 cubic yards per hour of fine mud or silt, dredged from a depth of 45 feet, and delivered, through 2,000 feet of 30-inch piping, to a height of 18 feet above the water-line. The single set of triple-expansion engines was direct-coupled to the pump. The cylinders were 21 inches, 30 inches, and 45 inches in diameter, and the stroke was 22 inches. The boilers were limited in size owing to the heaviest load that could be dealt with in the Karachi workshops being 30 tons. They were four in number, single-ended, of the cylindrical marine type, each having three internal corrugated furnaces, a total heating-surface of 5,480 square feet, and a working-pressure of 160 lbs. per square inch. The cutter was of the Robinson improved type with spiral blades driven by a 240-HP. engine. The floating pipes, 30 inches in diameter, were supported by two 39-inch cylinders, one on each side of the pipe; they were connected by cast-steel ball-and-socket joints and were built in 90-, 54- and 26-foot lengths. The short lengths were provided for sharp curves when dredging in restricted areas. In all about 1,700 feet of floating pipe and 3,700 feet of shore pipe had been provided. The total cost of the dredger and pipe-line complete was £95,000, including erection in Karachi. The dredger had now been working for a year, and it was remarkable through what material the cutter would work. Unfortunately, nowhere had so large a quantity of fine mud or silt been met with as to enable trials to be run under contract conditions. The material dredged consisted of beds of fine silt, sand, and shells, very heavy sand (practically gravel), blue clay,

Mr. Culbertson.

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Mr. Culbertson. yellow clay, and finally 4 or 5 feet of conglomerate of various degrees of hardness. Working through 20 feet to the conglomerate, rather more than 500 cubic yards per hour was dredged, and when working to a depth of 25 feet below low water, that was, through 4 to 5 feet of hard conglomerate, between 200 and 250 cubic yards per hour, with about 2,000 feet discharge. When working in conglomerate the steel cutter-blades wore at the rate of about 1½ inch per month, showing the extreme hardness of the material. Discharging at 4,200 feet, the dredger averaged about 200 cubic yards per hour. During 1915–16, 471,333 cubic yards had been dredged, at the average rate of 205 cubic yards per working-hour (including washing out pipes) discharged to an average distance of 2,804 feet. It was hoped to show considerable improvement on these figures this year, as last year more than a third of the time was spent in washing out choked pipes, owing to heavy material and many bends in the pipe-line, due to the restricted area in which the dredger had to work. So far the average this year had exceeded 400 cubic yards per hour.

Mr. Cullen. Mr. E. A. Cullen considered that the Author's insistence on the use of mattresses had been fully warranted. The strata on the site of the wall would appear from the borings to be very susceptible to erosion, and with currents reaching a velocity of 6 knots diverted through 90 degrees on a radius of 6,000 feet, the extent to which erosion would occur could not have been predicted. In the Brisbane River, the improvements of which Mr. Cullen had directed and been responsible for since 1893, there were several bends varying from 90 to 160 degrees, and with radii of 1,600 to 2,700 feet. In each of these bends the concave side was a rock bank preventing further erosion, and the maximum depths in each case ranged from 80 to 120 feet. These depths were maintained by the action of tidal currents not exceeding 2 knots. With the physical conditions at Rangoon it seemed to him that the use of mattresses was a very wise and necessary precaution. In one of the training-walls of the Brisbane River which crossed a sandbank awash at low water, a trench had been dredged ahead of the stone to enable a sufficient volume of stone to be placed to obtain an adequate section; and he would ask whether, in view of the risks from erosion, the question of providing a larger volume of stone in the wall by dredging ahead where it crossed a shoal with 5 feet over it at low water had been considered. In another wall in the Brisbane River, built in 1899, a section about 2,000 feet long was built on a soft mud bottom of great depth. Mattresses 100 feet long, 3 feet thick, and of various widths up to 40 feet, were constructed in manner almost identical

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Mr. Cullen. with that described by the Author, and were superposed three high; these were smothered in sand, a skin of stone was placed over all, and a stone bank of ordinary section was then built on top up to high-water level. Very little settlement occurred. These mattresses were built of mangrove which grew near. As this mangrove sank when green, and perished rapidly if exposed to air after being cut, it was necessary in using mangrove to make and place the mattress within, say, 3 months after cutting. The Author's statement about the volume of silt carried up the river on the flood-tide was interesting; the same fact was observed, but in much less degree, in the Brisbane and Fitzroy Rivers in Queensland. It had a significant bearing on the question of opening basins or docks off a river which had a deltaic mouth exposed to wave-action. The Author's experience with the wall as projected to less than half-tide level was so conclusive, and the inefficiency of a wall not raised to high-water level was so clearly demonstrated in the Paper, that probably the value of low-level or half-tide walls as regulating agents would be more correctly estimated as revetments. In the Brisbane River the areas behind the training-walls had been largely used as receptacles for dredgings from pipe-line dredgers, and it was found that when the walls were not up to high-water level the material leached through and a gradually receding beach was found inside, unless the wall was rendered sand-tight by clay backing. In the alignment shown in *Fig. 6*, as proposed by the Committee of 1906, the width of channel provided was about 650 feet less at the lower end than at the upper end, that was to say, a contraction of that amount was contemplated at the lower end in a tidal river. The reasons for the recommendation of an alignment which would apparently violate a fundamental rule of river-regulation were not to be gathered from the information in the Paper, and the Author was to be congratulated on having successfully opposed that proposal.

Dr. Cunningham. Dr. Brysson Cunningham remarked that the work described in the Paper constituted a monumental tribute to the enterprise and foresight of those who planned it. It would ill become anyone not thoroughly familiar with all the local circumstances to offer any criticism on the design, which, from the evidence adduced, had abundantly justified itself. At the same time, having regard to the enormous outlay entailed, especially when compared with the resources of the Port, it was permissible, perhaps, to wonder whether a scheme of such magnitude was essential in its entirety, and to ask whether a tentative policy might not have achieved ultimately results similar in character, at less cost. The evil evidently originated in the soft and erodible nature of the strata

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Dr. Cunningham. just below Seikgyi Village, where the stream from the reach above the village impinged directly upon the left bank at the point of entering upon the curved portion of its course. The action had been proceeding for many years. The chart of 1824 was stated to show the river as being of normal width. Presumably at or before that date the bank had been of a more resistant character, as the process of erosion had evidently been slow for a number of years. Subsequent to 1877 it seemed to have become rapid, with the result that between 1877 and 1913 the line of the concavity receded over 1,500 feet at the centre. As this effect was due to the inability of the left bank to withstand the erosive action of the current, particularly where the change of direction took place, the question arose whether a short training-wall at Seikgyi would not have sufficed to divert the stream into its original direction tangential to Mower's Point. The centrifugal action would then have ceased to be operative, and the erosive influence along the bank would have been eliminated. It was, of course, well known that small obstacles in the bed of a stream produced quite disproportionate effects. The channel of the Mersey, for instance, pursued a variable course through the sands of the inner estuary between Runcorn and Liverpool, and even so slight an obstruction as a stranded barge had been known to set the stream working its way across from one side of the estuary (which at its maximum was 3 miles in width) to the other. Probably the feasibility of such a curtailment of the training-wall at Rangoon had received due consideration at the time, but as there was no mention of it in the Paper, perhaps the Author would kindly state the reasons which had led to its abandonment. The effect of the wall on the Hastings Sand would be a matter for careful observation. The scouring action proceeding in the new bed of the river entailed the transportation of material to some quiescent place of deposit—probably in the neighbourhood of the shoal, or a little lower down-stream. Unless, therefore, it was carefully watched and dealt with, the growth of the shoal might shortly constitute a serious impediment to navigation. Dredging operations could, of course, be resorted to, but these would produce merely transitory amelioration, and further permanent training-works would appear to be almost inevitable.

Mr. Jordan. Mr. Wm. Leighton Jordan remarked that the Paper showed that the Rangoon river as it approached Rangoon had in recent years been abrading its right bank, and evidently threatened to change its channel in such a manner as to abandon the bend eastward which carried it along the south front of the town. The action described in the Paper so clearly accorded with what he had

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described[1] as a natural consequence of the earth's rotation that some special remarks on it seemed appropriate in this discussion. As the river was flowing from north to south, the abrasion of its right bank was what the earth's rotation must always have been tending to cause in that latitude under the action explained in Hadley's theory of the Trade Winds; and the abrupt bend from a southward to an eastward course, which carried it past the town, must have been caused by some resisting material which had in recent years been swept away, leaving softer material for the current to work on. The Author's embankment constituted an artificial restoration of such a natural obstruction as must originally have existed to force the river eastwards from its natural course. Mr. Jordan.

Mr. J. C. LARMINIE observed that, apart from its general interest, the Paper would appeal specially to engineers who had had to deal with any of the large Indian rivers. But few, if indeed any, other engineers in the course of an Indian career had been so fortunate as to hold almost independent control of a work of such magnitude and interest. Without personal experience of the Rangoon river and knowledge of local conditions it was not easy to criticize or make suggestions, particularly when the work had been so skilfully carried out under trying climatic conditions, involving much exposure and physical strain, and had, above all, achieved its designed purpose. Of the general features of design and execution two seemed especially open to discussion, namely, (*a*) the provision of mattresses as a foundation, and (*b*) the opening of new quarries on a desert island 135 miles by sea and river from Rangoon. In regard to (*a*), it would appear that the river-bed, along the line of the training-wall, was of a fairly stable, firm character. No mention was made of any tendency to scour along the edge of the mattresses when they were first weighted into position, or subsequently as the wall was raised. Consequently it did not seem probable that the omission of the mattresses would have caused any material difference. No doubt the mattresses tended to bind the bottom layers of stone together, and so afforded a regular footing to start from; but with ordinary rip-rap the same result would have been attained after a slight settlement, and possibly the loss of a small quantity of lighter stone swept away by the current; but against this slight expense in stone had to be compared the expense, trouble, and delay due to the Mr. Larminie.

[1] "The Discharge of Sewage in Dublin Harbour." Minutes of Proceedings Inst. C.E., vol. cxlvii, p. 145. Also "The Ocean; its Tides and Currents and their Causes." London, 1873.

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Mr. Larminie. mattresses. As a matter of fact, what would form a foundation for 2,700 feet of wall had been laid subsequently, between Mower's Point and the end of the wall proper, apparently without mattresses. In regard to (*b*), the deciding factor in favour of Kalagouk quarries would seem to have been that the Author, in opening them, obtained complete control of the supply of stone—a very satisfactory arrangement to start with. But without the light of previous experience, had not a serious responsibility been incurred in undertaking so large a capital expenditure and the risks and delays that might have arisen in transporting stone by sea during the monsoons, in preference to the land-locked route afforded by the railway quarries? To work the latter effectively no doubt some capital expenditure on plant would have been required; but such plant would remain available for further use, and so loss entailed by sale of sea-going plant would have been avoided, as also the cost due to maintaining a large camp on an unhealthy island. A remarkable feature of the work was the close agreement of the estimated quantity of stone (28 million cubic feet) with the amount used (27,943,000 cubic feet).

Mr. Lyster. Mr. ANTHONY G. LYSTER, Past-President, stated that he found it necessary to elucidate his remarks in the Discussion with the following additional observations. In his opinion the omission, to which he had drawn attention in the Discussion, of charts showing the condition of the river-channel abreast of Rangoon before and after the completion of the training-work, robbed the Paper of a great deal of its value, as it left The Institution without any graphic representation, such as engineers invariably required, of one of the chief effects produced by the work, and which would afford the best justification for the very serious expenditure incurred. He thought this omission should be made good by the Author, and that charts covering the length of the river between the upper end of the work and Pazundaung Creek, or so much of that length as was regularly surveyed, showing the conditions immediately before the commencement of the work and as late as possible after its completion, should be furnished; and if any current observations had been taken at corresponding times these would also be of great interest. He had examined such of the Admiralty charts (to which Mr. Meik had referred him) as were available, namely, that for 1903–1904 and that for 1913–1914. These were to a small scale, and being only for general navigation purposes did not give such complete information as no doubt was available on the local surveys, which would also afford a better engineering comprehension of the relative condition of the river at the two periods. So far as they went, however, the

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Admiralty charts indicated by the comparative depths that the scour along the upper end of the jetties on the Rangoon bank was apparently at the completion of the work greater than when the current ran round the bend above Mower's point. The midstream depth off Mower's point had, however, diminished. At the lower end of the Rangoon bank there seemed to have been substantial shoaling over a very considerable area at the later date, the 3-fathoms contour having advanced up-stream as much as 500 yards. If, therefore, these changes were confirmed by the larger-scale local charts, which no doubt contained a much larger number of soundings than the Admiralty charts, and the tendency was shown to continue in the most recent surveys, the "undermining of the Port Commissioners' wharves and jetties," the prevention of which was one of the chief objects of the training-work, had evidently not been arrested so far as the higher of those works was concerned, whilst those farthest down-stream seemed to be in danger of being shoaled to an inconvenient extent. This result, assuming that it was borne out by the evidence of the larger and later charts, was by no means inconsistent with the lay out of the training-wall and the effect which might have been anticipated from the altered direction given by it to the current. According to the well-known and well-established law governing a current running round a bend, the stream was given a helical motion due to the water surface of the concave side of the channel being raised above the level of that on the convex side, following the centrifugal force set up in the stream as it ran round the bend. The current running round the bend formed by the Rangoon training-wall, which subtended an arc of nearly 90°, would therefore not continue in a straight line down the river past Mower's Point, as the Author seemed to expect, but would be rolled over in a sort of helical undertow, which would result in strong scouring action along the Rangoon bank. This action could be traced in any untrained river flowing through alluvial material, by the sinuosities which were developed in its course in the form of alternating reverse bends. The scouring force set up by this action at Rangoon would be much greater after the establishment of the training-work than before, because the flatter curve of the training-work would not absorb so much of the current energy as did the old and more intensified curve of the concave river-bank above Mower's Point. Examination of the depths shown on Figs. 11 and 13, Plate 5, would illustrate the correctness of this statement. In the first chart, taken after the work had progressed considerably, the contours showed that the river-bed alongside the concave bank had deepened to 80 feet below datum Mr. Lyster.

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Mr. Lyster. over a considerable area. In Fig. 13, showing the condition after the completion of the work, the area within the 60-feet contour was greatly contracted, and there were no depths of 80 feet. The result of this was that the current potential tending to form a reverse curve abreast of Rangoon would be greater now than formerly. This current would, however, take effect in a more oblique direction to the Rangoon bank than it had done under the original conditions, and the only satisfactory way of determining under which condition the greatest scouring effect was experienced at Rangoon was by comparing the charts abreast of that place before and after the construction of the work. The Author seemed to have based the principle of his work on the very reverse of the elementary law referred to above, for on p. 150, in dealing with the results of the erosion of the concave bank, he said :—(2) "The ebb tide, swinging round the eroded bend in a deep contracted channel, has emerged from it at the projection known as Mower's Point with great force, and the momentum thus given to the water has carried it obliquely across the river to the Rangoon bank, causing erosion of the river-bed and undermining of the Port Commissioners' wharves and jetties." In other words, he seemed to hold the opinion that the stream derived an increase rather than a diminution of energy from running round a bend. If this were so, of course, all railways, in the interests of economical traction, ought to be built in a series of curves and all rivers trained in a similar manner. It was hardly necessary to dwell on the fallacy of such a view, but it was desirable that it should not go unrefuted in the Proceedings of The Institution. It also made it all the more desirable that the effect of the work should be established by the evidence of the charts. Where such information was available it would be a mistake to dogmatize unduly on the probable effect at Rangoon of this new work or that of the alternative which he had suggested as worthy of consideration. Much more information also than was given in the Paper would be necessary before a definite opinion whether the stereotyping by revetment of the river-channel above Mower's Point in 1904–5, and the protection of the Rangoon bank, would or would not have met all the requirements of Rangoon and given as satisfactory results as the present work. It was quite certain that it would have satisfied the most important requirement, namely, the prevention of the cutting-through of a new channel behind Mower's Point. It was equally certain that the revetment of the Rangoon bank could, as he had suggested, have been readily and economically carried out, and would have arrested any scouring action there. Mr. Meik in his remarks had admitted that this

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Mr. Lyster. work would have been a necessary adjunct to the revetting of the curve above Mower's Point. It was also beyond doubt that these two works conjointly would not have cost anything approaching the amount spent on the training-works—probably not more than one-fifth of that sum—and would have been carried out in very much less time. The only other questions in doubt were: (1) What advantages had resulted from the existing works which would not have been obtained by simple revetment? and (2) were these advantages, if shown to be established, worth the very large extra amount which they had cost, namely, about £700,000? These questions might be definitely settled if the charts and current observations were furnished. The matter had been brought before the notice of The Institution, and it therefore seemed very necessary in the interests of the difficult science of river hydraulics, for knowledge of which engineers depended so largely on practical experience, that the ascertained and probable future effects of this interesting but very costly work on the port and river of Rangoon should be more fully and clearly established than they had been by the Paper.

Mr. Samuelson. Mr. B. M. SAMUELSON remarked that he had had the privilege of visiting this unique work periodically, from the laying of the first mattresses to its final completion, and he congratulated the Author upon the rapidity with which it had been constructed, and the manner in which the difficulties had been overcome as they had arisen. The area of the Irrawaddy delta was 21,000 square miles, not 27,000 square miles as given in the Paper. He asked whether the fresh-water discharge of the Rangoon river, as given on p. 148, included also the discharge from the Pegu and Poozoondaung rivers. The spill from the Irrawaddy to the Hline river was measured by him, during a medium high flood, in August, 1914. The average was 125,000 cubic feet per second, but the maximum spill amounted to about double that quantity. The silt-contents were measured at the same time. The mean value at Saiktha and Donabyu, 120 miles apart, was 1 in 1,840 parts, by weight. The ratio varied considerably from day to day, the minimum being 1 part of dry silt in 3,740 parts, and the maximum 1 in 1,126 parts. The cause of the small amount of silt brought down by the Hline river when in flood was that the more northerly tributaries, which were heavily laden with silt, spilled broadcast over the plain, and deposited their silt before the flood-waters reached the Hline river. The plain was being gradually reclaimed, and the time would come when the silt would be discharged into the parent stream: the Rangoon river would then no longer be so free from silt as it was at

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Mr. Samuelson. present. Why had a broad toe been allowed behind the training-wall in the shallow sections, while no such provision had been made in the deep-water sections? The reduction in the hydraulic gradient behind the training-wall was similar to that noticed near Henzada in 1911, when an attempt was made to block a side channel and to force the main channel away from the town. The river burst through a shallow cross channel about $1\frac{1}{2}$ mile below the upper training-works, and impinged directly on the unprotected foreshore, carrying away a considerable width of land covered with valuable property. The effect of creating a backwater had not been foreseen. Did any record exist of the condition of the Kanaungto Creek from early years? The gradual increase of the curvature of the river-bank would raise the head at the mouth of the creek and would increase the tidal flow, thus tending to induce scour. The training-wall had caused the conditions to revert suddenly to what they were in 1824, and the length of the creek had been increased by nearly a mile. The tidal head had been reduced, and the embayment behind the wall was rapidly silting up. It would appear that the Kanaungto Creek must follow suit, to the detriment of the many valuable rice-mills now situated on its banks. Any information the Author might be able to give as to the effect of the training-wall upon the regime of the Kanaungto Creek would be of great interest.

Sir Francis Spring. Sir FRANCIS J. E. SPRING, K.C.I.E., congratulated the Author on the perfect lucidity of his Paper, which described an engineering work unique in character and, so far as he knew, the largest of its kind ever carried to a successful issue. So successful had the work been in its results, and so thoroughly had it been carried out, that there seemed to him to be nothing in the description of it that laid itself open to criticism. Possibly another method might have been as successful as the one described, but it was impossible to predicate such success, and all that could be said with certainty was that the method adopted by the Author appeared to have been admirable in all respects. At the end of 1903 he paid his only visit to Rangoon, and although on that occasion merely holidaying, he had a talk with the Author about his great scheme for preventing the river from leaving the city wharves high and dry. The impression he then formed was that somehow or other Mower's Point—whether from small detailed attention to maintenance of the river-bank thereabouts, because of saw-mill interests, or otherwise—had got itself held, as it were, instead of being cut away, as in the natural course of things would have happened; and the result was that, sticking out as a permanent spur, it had caused the erosion of the river's right

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Sir Francis Spring.

bank, which it had cost about a million sterling to cure—a great erosion not harmful in itself except in so far as it was found to cause harm to the left bank farther down-stream where shipping and property interests of high value were threatened with irretrievable injury. At a great city like Rangoon or Calcutta it would be unpermissible not to prevent, by all available means, the occurrence of changes in river regime such as occurred year after year, with little or no notice, in the courses of the Ganges, Indus, Brahmaputra and other big rivers at places where no other than agricultural interests were involved—and those often, indeed, advantageously for themselves. Members interested in it would find the subject of the vagaries of many of the great Indian rivers dealt with in his book, "River Training and Control,"[1] in connection with the necessity not, as at Rangoon, of preventing such vagaries, but of holding the rivers in question beneath the great railway-bridges that spanned them. River-training for bridge purposes was a different problem from that presented to the Author for solution, though sometimes, as in the case of the Lower Ganges bridge—on which it was to be hoped that a Paper might soon be presented to The Institution by its builder, Sir Robert Gales[2]—it was a problem of proportionately very great magnitude. But both had much in common in their big stone-supply, the labour problem, the river-scouring problem, the silting-up problem, and so on; and it was because of these factors common to both classes of work that, since its inception, he had taken the greatest interest in every part of the Author's big work, in so far as information in regard to it had been accessible to him. As already described[3] in the Proceedings, he completed a few years ago "departmentally," as it was called in India, that was, without the intervention of any but the pettiest contractors, a scheme of works for Madras Harbour costing about half a million sterling. Since then, and to the present date, he had had in hand further works costing well on towards another half-million, also on the "departmental" system. These last, including a quay costing about £200,000, he hoped soon to describe to The Institution. His object in referring to them here was to lend the weight of his evidence to the Author's in regard to two matters of high import-

[1] Simla, 1903. Also Technical Paper No. 114 (Railway Dept., Govt. of India).

[2] Such a Paper has now been received.—Sec. Inst. C.E.—Oct. 1916.

[3] "The Remodelling and Equipment of Madras Harbour." Minutes of Proceedings Inst. C.E., vol. cxc, p. 89.

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ance in such work as this; first, that in works of the sort, in India, the intervention of the big contractor, apparently so necessary in many other parts of the world, was undesirable and unnecessary if the engineer was willing—as he himself always had been—to give personal attention and experience to the management of the big crowds of native labour; and secondly, that much of the Author's success with the work in question must be ascribed to two causes, namely, that the Chairman of the Port Authority and the Engineer of the special works were one person, and that a separate department and distinctive accounts were kept for the works in question. It was on these lines that he had worked for the last 10 years out of the 12 he had spent at Madras Harbour, and it was to the adoption of these administrative methods that he ascribed not only the absence of litigation in matters of works, but also the perfect smoothness and absence of friction and red tape in his relationship, as regards construction works, not only with Government but also with the Port Authority, with whom he served as "Engineer-Chairman," as the Author did at Rangoon. Amongst the most interesting matters he found in the Paper were: the tidal model and the results obtained from it; the decision greatly to modify the regulation permeable dam, or screen; and the success of the flexible brushwood mattresses. The 4 years of discussion at the hands of experts and others and the way in which the initiation of the Author's scheme had been delayed, while all the time the condition of the river was becoming worse and worse, reminded him of the interminable paper discussion over the best shape for the Madras Harbour breakwaters. It was enough to take the heart out of an engineer who knew his job and had confidence in his judgment, to feel that at any moment some minor official or unprofessional person might interfere and delay matters. The description of the island quarry at Kalagouk and the scheme for working it, and of the difficulties encountered, was very instructive. He could to some extent appreciate the magnitude of the arrangements, having for Madras Harbour had to quarry about half the quantity dealt with by the Author at an all-over rate of about 5*s*. per ton, or £1 5*s*. per 100 cubic feet—varying largely of course in accordance with the character of the stone. The mattress idea might later afford valuable wrinkles for the river-training needed for great bridge work. But of course the material that happened to be available in the immediate locality of the work, whether pine trees as in much American work, or bamboos, or brushwood, was a matter of vital importance, for such stuff could not afford much railway freight. The lucid description of the making, launching, and sinking of the mattresses was extraordinarily

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interesting, as was also the use of the reinforced-concrete permeable screen, in substitution for the regulation netting and timber one. The Author did not explain how his stone quantities were measured. They were given in cubic feet and the rate was worked out per 100 cubic feet, but nothing was said as to whether the cubic feet included voids in the stone as laid in the work, or represented the solid in the quarry: presumably the former was the case. In the Madras Harbour works all stone was passed over an automatic weighbridge, arriving conveniently in wagons; and when rates were wanted per cubic foot the ratio "20 cubic feet to a ton" was applied, as the result of many experiments, the cubic feet in question being those of the stone loose in stack or in place, and not in the solid. The Rangoon Port Authority, the Burma Government, and the traders of that progressive province had been fortunate in their decision to give the Author practically a free hand. Sir Francis Spring.

Mr. E. W. STONEY congratulated the Author on the successful execution, well within the estimated cost, of a work of unusual novelty, magnitude, and difficulty, and considered that the greatest credit was due to the Author for the courage and resolution with which he had adhered to his well-thought-out opinions and design, in spite of adverse criticism. He agreed in the wisdom of the Author's decision to carry out the work departmentally, thereby reserving to himself a free hand to deal with difficulties as they arose, and to alter his designs as experience suggested. Mr. Stoney.

Mr. G. W. SUTCLIFFE observed that the Yorkshire Ouse presented many points of similarity with the Rangoon river. The depth of water along the line of wall was nearly the same. The tidal currents were fairly comparable, but the greater sharpness of the curve in the case of the Ouse must naturally cause more irregularity in the stream. The bed and banks ranged from silt to coarse sand in each case, with the addition of "warp" in the Ouse. The angular measure of the deep wall was almost identical in the two cases. In fact, the problems were singularly alike, except that the Rangoon wall was nearly three times as long, and its radius of curvature three times as great as in the case of the Ouse wall, which was a very important advantage. The principal features were compared in the following Table:— Mr. Sutcliffe.

		Rangoon.	Ouse.
General width at low water	feet	1,700	700
Depth at low water along line of wall	,,	40	44
Watershed area	,,	27,000	4,500
Rise of ordinary spring-tides	,,	17	15
Velocity ,, ,,	feet per second	13	9
Main curve, radius along wall face	feet	6,000	2,050
,, ,, angular measure		81°	84°
,, ,, length along curve	feet	8,500	3,000

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Mr. Sutcliffe. All the Ouse walls were built of slag, which obviously was not available at Rangoon. Granite and slag were however both of igneous origin, and, although both were liable to variation, it was probable that the specific gravity was approximately the same. The Ouse walls were built without faggots or mattresses in the foundation. The work was commenced at each end nearly simultaneously, single guide-piles of whole pitch-pine being driven 60 feet apart along the line. A few hopper-loads of slag were first dropped in approximate position, and the pile was then driven by an ordinary pile-driver mounted upon a barge. This operation was facilitated, and greater accuracy was secured, when the uppermost load to receive the pile was of what might be termed friable slag from a slag-cooling machine. Scores of these piles were knocked adrift by shipping, but they were usually recovered and re-driven, so that the loss and delay which resulted were negligible. A few piles were however broken off and had to be replaced. The piles stood above equinoctial high water to mark the walls, and in positions of importance they carried lamps. Dolphins or braced steel piles 500 feet apart would have been costly and would probably have proved a failure in this instance. The slag came from Middlesbrough blast-furnaces, and was broken to a handy size to pass freely through the hopper-doors. It was brought by sea in hopper-barges, each vessel carrying normally about eighty loads per annum, of 400 to 450 tons each. The hoppers discharged through side doors the lower edge of which was a little below the upper turn of the bilge and so placed as to avoid any interference with the full strength of the floors of the vessel. The space beneath the cargo space was utilized for water-ballast tanks which were used in trimming the ship when one side of the cargo was tipped. A centrifugal pump was used to fill or empty the tanks. On several occasions severe wintry weather caused the water to become charged with frazil ice, which choked the suction gratings, the mesh of which had to be changed to the widest that would protect the pumps. By the adoption of side-discharging hoppers very large quantities of slag were deposited in position without any of the hand trimming which would have been necessary if bottom delivery-doors had been adopted. Moreover, repairs and overhauling were less frequent and less costly in labour and delay. The same might be said as to the results of misadventures in navigation. In one case a loaded hopper in a storm was driven over a training-wall in the Tees; the cost of salvage and the necessary repairs would certainly have been much greater had the hopper possessed bottom doors. Possibly two hoppers might have been replaced by one of

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Mr. Sutcliffe. 1,000 tons with advantage in some respects, but having regard to the conditions attendant upon the loading and discharging of the cargo, the net result was very doubtful. The work in the Ouse, like that at Rangoon, was carried out by administration, without contractors, but obviously the necessity of wholesale provision for housing workmen did not arise. The Ouse deep wall overlapped—by a distance of about 200 feet—the apex of the point at low water as existing before the commencement of the work. The point had therefore to be scoured away as the work proceeded from each end, and progress at the ends had to be adjusted so as to avoid upsetting the balance. This was continued until a depth, at low water, of about 40 to 44 feet was scoured out, at which the depositing of slag was commenced. The whole of the slag below low water and a large quantity above low water was dropped in position from the hoppers, but the top work and the facing were laid by hand, for which two flush-decked barges were used with a small tender or launch for towing; the slag for this purpose was taken from the tops of the loads in the hoppers. Practically, the slag was unselected, and no concrete or other special material was used for facing, so that such small subsidences as did occur were easily treated by addition of material. Both the Rangoon and the Ouse walls were in the main length built to a circular arc. In the Ouse the positions for successive piles were determined by sextant. In each case the positions of two preceding piles were taken accurately, and the new pile was set by alignment from the two existing ones. Sometimes one or both of these would be knocked slightly out of position or verticality, but the adoption of the "angle in a segment" method always sufficed to correct the position. The use of continuous arcs for alignment of training-walls was open to serious objection on account of the abrupt character of the changes usually involved. The objection might be largely overcome by stepping down in a succession of arcs of increasing radius—or conversely; but it could only be properly met by the adoption of transition-curves. There was no necessity for any closely-defined distinction between cubic parabolas, simple parabolas, elliptical curves, etc.; all that was necessary was regular variation in the virtual radius of the curve. The late Professor R. H. Smith had prepared a set of curves with constant variation per unit of length of curve which appeared to meet the case best, and which possessed the merits of simple notation and facility of application. Many other systems were, however, available for choice. Obviously, the adoption of transition-curves would involve corresponding modifications in the method of locating positions by

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Mr. Sutcliffe. sextant. On p. 174 the Author stated three disturbing causes which combined to produce variations in the level plane surface of the stream, and the principal one was given first. The head—or cross slope—was stated to be calculated as 3½ inches, which was only one-third of that in the Ouse. Rough observations, taken during the progress of the work, were in substantial accord with calculated figures. The cross slope might be termed superelevation, as in the case of railway-curves. Water flowing in a straight channel was in transverse equilibrium when the surface was level across. Transverse equilibrium was again obtained with a cross slope or superelevation of about 1 foot in a stream under the following conditions:—Radius, 2,050 feet, width 700 feet, velocity 9 feet per second. A sudden change in radius involved an equally sudden change in the superelevation needed for equilibrium under the new conditions. If less superelevation was now required, the energy stored in the water must assert itself, and disturbances were produced in the stream of such magnitude as to seriously affect the navigation of vessels and the uniformity in depth of water. The only satisfactory method of eliminating such irregularities was to eliminate abrupt changes in each direction. The Author was definite as to the disappearance of the cross currents from Mower's Point; but however good the present condition of the river might be, it was beyond doubt that it would be distinctly better if suitable transition-curves had been adopted. Probably the majority of railway-engineers were convinced as to the superiority of transition-curves *per se*, and were only deterred from adopting them more largely by difficulties in connection with the accurate bending of rails and the general conditions of construction, which reasons were not in any way represented in connection with river-training walls. There did not appear to be any reason to suppose that the Ouse walls would have benefited by the adoption of mattress foundations. It was, however, a debatable point what advantage would have been secured by the use of friable slag to effect a general reduction in the amount of scouring allowed in the first instance. Used with discretion, this material might be deposited in the navigable channel without leading to difficulties with anchors or causing damage to the bottoms of vessels. It was used in temporary positions, and when automatically filled by "warp" from the river it was found to be surprisingly successful in resisting scour. The Ouse walls were designed by Mr. W. H. Bartholomew, M. Inst. C.E., in accordance with the terms of the Ouse Improvement Act passed in 1884. The work was commenced soon afterwards, and several miles of comparatively shallow wall were built before March, 1889,

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at which time Mr. Sutcliffe entered into executive charge under Mr. Bartholomew, continuing therein until July, 1892, when the whole of the deep wall had been laid to above low water and almost completed. Mr. Sutcliffe.

*** Circumstances have prevented the Author from making his reply to the Discussion and Correspondence before this volume goes to press, but it is hoped to include the reply in the next volume of Proceedings.

Mr. C. S. Meik, who represented the Author when the Paper was read before The Institution, has submitted the following interim remarks upon the Correspondence.—SEC. INST. C.E.

Mr. C. S. MEIK hoped that the Author, who had been away from Rangoon on active service in Mesopotamia since the autumn of 1915, would reply fully hereafter to the Discussion and Correspondence; but under the unusual circumstances, and as his firm had acted as Consulting Engineers for the work since its inception, he felt justified in offering some interim remarks on the criticisms dealing with the design and the general features of construction. It appeared to him that some of the critics, and Mr. Lyster in particular, had overlooked the fact that the result of the construction of the training-wall had been, not to establish a new channel for the river, but to restore it to the course it actually followed in the early part of the nineteenth century and for many years previous to that time. The river-channel, as it now existed above Rangoon, was much the same as that shown on the plan of 1824, referred to in the Paper. The restoration of the channel to its original course, by the construction of a training-wall, had been recommended by all the engineers consulted, and was undoubtedly the correct solution of the problem. Sir John Benton's remarks were instructive in this respect, and no one had a better acquaintance than Sir John with the Rangoon river before the construction of the works. Mr. Meik presumed that the "well-known and well-established law governing a current running round a bend" of a stream, to which Mr. Lyster had alluded in his supplementary remarks, was the theory propounded by the late Professor James Thomson to the Royal Society in 1877, and described in Dr. Unwin's "Hydraulics." This theory, which had been confirmed by experiments on a model, explained how the concave side of a river-bed scoured away and the convex side accreted owing to the action of subsidiary currents; but it did not suggest in any way that this action affected the main body of the water in the channel, and Mr. Meik therefore could not follow Mr. Meik.

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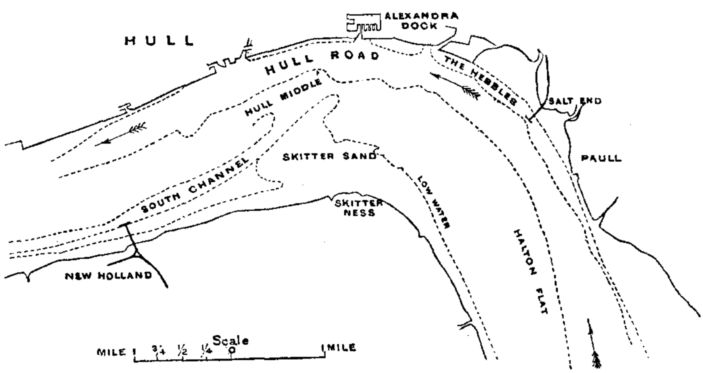
Mr. Meik. Mr. Lyster's reasoning when he stated that the current, after following down the training-wall, "would be rolled over in a sort of helical undertow, which would result in strong scouring action along the Rangoon bank." Such information as Mr. Meik had in his possession tended to show that scouring action had taken place under Mower's Point, as was to be expected. In support of his contention Mr. Meik would instance the River Humber immediately below Hull (*Fig. 23*) where the configuration of the channel was similar to that at Rangoon. In the Humber the centrifugal force of the flood-tide rushing round the curved channel between Paull and Hull caused the water to press outwards and heap up so that over a considerable period of the flood-tide the water-level at the Alexandra Dock entrance rose as much

Fig. 23.



as 19 inches higher than the water-level at Skitterness on the south side of the river, the distance between these points being less than 2 miles. This water gradient was sufficient to set up subsidiary cross currents at the bottom of the channel and under the main body of water, in the direction of the axis of the curve or bend. These subsidiary currents, in addition to causing the Skitterness sand to accumulate in the manner suggested by Professor Thomson's theory, kept open the secondary channel to the south of the Hull Middle Shoal. They did not, however, affect the main body of the flood-tide which flowed up through the Hull Road channel (*Fig. 23*) on the north shore of the Humber as far as the west end of the Hull Docks embankment. If the action of the flood tide in the Humber opposite Hull were taken as a precedent, then the ebb-current at Rangoon, after passing the end of the training-wall, would maintain the principal channel on the south

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side of the river. Further, any such current action at Rangoon as that predicted by Mr. Lyster could take place on the ebb-tide only, as the flood-tide had a straight run up through the harbour below Mower's Point, and the flood-tide had an equal if not a greater effect than the ebb-tide in maintaining the regime of a river. **Mr. Meik.**

Sir John Benton had raised the question whether the alignment of the wall was the best under the circumstances. In Mr. Meik's opinion this had been the most difficult to decide of all the points that had arisen in connection with the design as a whole. It had been obviously not desirable to contract the width of channel too much, as by doing so scour would be accentuated and tidal water, so necessary to the preservation of the channels below Rangoon, would be excluded. On the other hand, by making the width too great, cross currents might have been set up in the anchorage, and siltation caused along the river-front. Should it be proved hereafter that the width allowed had been too great, a remedy could easily be found by reclaiming land on the north side of the harbour to a greater extent than was originally intended, and so narrowing the channel alongside the wall. On the other hand, had the channel been made too narrow to begin with, a remedy would only have been possible at an excessive cost. As to the mattresses, he had already pointed out in the Discussion that they were originally introduced into the design by the late Mr. P. W. Meik, owing to the fact that laterite was intended to be used in the wall. When granite was found to be available, mattresses were not required, except possibly as a foundation-course to provide protection against scouring action. The much-debated point of the necessity of mattresses in the work had been referred to by many correspondents, and, judging by the opinions expressed, the Author appeared to have followed the correct course in adopting them.

Referring to Mr. Coath's remarks, groynes, as a means of protecting individual sites on river-banks, were generally successful in their object, but, as a rule, were not appreciated by the riparian owner lower down the river. In the case in point, the construction of the groyne, as Mr. Coath pointed out, played havoc with the foreshore on the Rangoon side, cutting away large slices of the foreshore, together with several landing-stages. He could not call to mind any tidal river that had been successfully trained by means of groynes alone; his experience pointed the other way, and he could instance rivers where the attempt to do so had been tried and had proved a failure.

The Author would no doubt deal with the other points raised by Mr. Coath, as well as those raised by Sir O. Wheeler-Cuffe, but

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Mr. Meik. with regard to Mr. Coath's reference to the Hastings shoal, towards the end of his remarks, Mr. Meik would quote from the last Annual Report of the Commissioners of the port—for the year ending 31st March, 1916—which, in dealing with this question, stated:—

> "The suction dredger 'Cormorant' was kept in actual commission dredging for the whole of the year under review. Altogether in the Hastings channel and Danidaw reach she lifted 1,576,000 tons at a working cost of one anna a ton. The result was eminently successful, as all through the dry weather months a channel averaging 14 feet at low water was maintained across the Hastings shoal."

The approach to Rangoon Harbour hitherto had usually been by way of the Monkey Point Channel (Fig. 1, Plate 4), although at times the Hastings channel (lying more to the west) had occasionally been used. Both of these channels were subject to variation in depth, according to the season of the year, and no serious attempt had ever been made to improve them prior to 1914, when the suction dredger "Cormorant" was started on the Monkey Point Channel, with excellent results. As the dredger had recently been requisitioned for Government work elsewhere, dredging had been stopped in the meantime, so that it was quite possible that the channel might next year revert to its normal condition. The Rangoon Port Authorities were however quite alive to the fact that some steps should be taken to effect a permanent improvement in the channel through the Hastings shoal, and a comprehensive survey of the site had been made, and current observations taken, under the supervision of the Author, in 1914 and 1915. Had it not been for the intervention of the war and the absence of the Author from Rangoon, there was no doubt but that a scheme for the improvement of the approach-channel would have been formulated before now. He had hoped to be in a position to supplement the Paper with the further plans of the harbour referred to by Mr. Lyster, but owing to the circumstances mentioned at the commencement of his remarks, it had not been possible to do this. He trusted, however, that further information as to the state of the harbour of Rangoon, together with an account of the improvement of the approach-channel referred to above, would be submitted to The Institution in the near future.

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