

### CONCLUSION

With certain exceptions, the design and construction of the civil and mechanical engineering work were carried out departmentally by the Board's engineering staff, workmen, and plant. Mr T. L. Norfolk, M.I.C.E., was Engineer-in-Chief from the initiation of the scheme until his retirement in 1941, when he was succeeded by Mr Leopold Leighton, O.B.E., M.I.C.E., under whom the work was completed.

The gates, gate machines, and sluice machinery were designed by the Board ; the construction and installation of these items, and the design and construction of the foot-bridge, were carried out by specialist firms.

### ACKNOWLEDGEMENTS

The Author wishes to express his indebtedness to all those members of the staff of the Mersey Docks and Harbour Board who willingly gave him so much valuable assistance, and especially to Mr Leighton, who retired from the post of Engineer-in-Chief to the Board in November 1949, and to his successor, Mr A. B. Porter, M.I.C.E.

The Paper is accompanied by fifteen photographs and seventeen sheets of drawings, from which the half-tone page plates, the folding Plates, and the Figures in the text have been prepared.

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### Discussion

**The Author**, in introducing the Paper with the aid of a number of lantern slides, said that it had become clear during the years prior to the last war that both the Central and North dock systems would require new deep-water entrances. After some consideration it was decided to build the entrance for the Central docks first ; the Waterloo river-entrance was the outcome of that decision.

Work had already begun on the entrance for the North docks, which was situated in the vicinity of Canada basin. The first operation had involved the closing of the passage between Canada and Brocklebank docks. It was now impossible, therefore, for ships to proceed from the docks north of the passage to those south of it without first entering the river through the Gladstone river-entrance and then passing through the Waterloo river-entrance, which had consequently incurred very heavy use. About forty coasters used the entrance every day—a severe test from which it had emerged very creditably.

The largest class of vessel that used the entrance had a gross tonnage of about 4,300, a beam of 54 feet, and an overall length of 367 feet. It did not normally employ tugs.

On the flood at spring tides the stream velocity close to the wall was about 1 knot, and the maximum velocity of the stream was about 2 knots. There was a general tendency for the stream to cut in towards the wall, and this phenomenon, when combined with a strong westerly gale, was sometimes troublesome in that ships leaving the dock tended to be pinned against the wall. No particular trouble was experienced on the ebb, the stream velocities being lower. The river approach wall was provided with sluices, which were used at spring tides, when there was sufficient water available, and the fairway to the entrance generally maintained its depth down to sill-level without dredging. Shoals tended to form, however, just inside the mouth of the entrance and at a point off the south end of the approach wall. In the latter position accretion proceeded up to about 2 feet above sill-level and then apparently ceased; the reason for that was not yet clear, but it might be connected with the propeller action of ships depositing silt just out of range of the sluices. Observations were to be taken with the object of finding out why this shoal formed.

**Mr Leopold Leighton** said that, in view of the position which he had recently occupied, he would hardly be expected to make any criticism of the works described in the Paper, and he therefore proposed to deal with generalities, which were sometimes quite as important as details.

The Paper embraced all the fundamental principles that arose in modern dock-entrance construction and equipment. It was true that the entrance in question was of only moderate width, but it was of abnormal depth, and it was in connexion with depth that many of the problems of the dock engineer arose.

Dock entrances, once built, lasted for many years, and few engineers, therefore, had an opportunity to participate in such works. The Mersey Docks and Harbour Board had been fortunate in having, for the work described in the Paper, many of the engineers and foremen, and also some of the workmen, who had been concerned with the construction of the 130-foot-wide Gladstone river-entrance and the 80-foot-wide river-entrance at Birkenhead.

He had always considered that dock-entrance construction was one of the most interesting and important types of work that the dock engineer had to undertake; dock entrances were, however, important not only from the engineer's point of view but also from the point of view of those who guided the destinies of the dock systems of Great Britain, and, whilst considerable capital expenditure was involved in the construction of dock entrances, it was obvious that such expenditure had to be undertaken if British docks were to be enabled to meet present-day requirements.

Great economies could, however, be effected in many cases by a well sited and well planned new dock entrance. To make his meaning more clear, he would make special reference to the case described in the Paper. Through the construction of the new entrance, it had been possible to close the Salisbury half-tide river-entrance and the Princes North and South

half-tide river-entrances, together with the two barge locks, one at Salisbury dock and one at Princes half-tide dock. Three entrances and two barge locks had been closed, all of which had previously had to be maintained and manned continuously. Their work was now being done through the Waterloo river-entrance. That fact was of great assistance to shipping: half-tide river-entrances, as their name implied, were open for about 2 hours before high water and were closed shortly after high water, and the movement of shipping was thus seriously limited. Not only did the new entrance enable important express steamers to Dublin and Belfast to sail at any state of the tide, but ships on coastal services, whose voyages were of hours rather than days, could go out fully loaded at any time. That was the advantage of the modern deep-water entrance.

He considered, however, that, in the case of a larger entrance for ocean-ships, serious thought should be given to the depth of the sill. It was not vitally important to the ocean-going ship, which had perhaps made a 21-day passage, to dock at any particular hour; in fact, in many cases such ships would prefer to negotiate the approach channels at half-tide. Although it was satisfying to be able to claim to take a ship drawing 32 feet at dead low water, such ships, he suggested, often did not need to use the entrance at low water.

He had, in recent years, strongly advocated the adoption of rectangular sliding caissons for the modern large dock-entrance, and he still did so. He was, therefore, pleased to say that such caissons were to be fitted at the new Langton river-entrance and also at the large lock giving access to an important oil dock, now being built by the Manchester Ship Canal Company at Ellesmere Port. For an entrance 65 feet wide, however, the steel gates were quite satisfactory, and he would not employ caissons, which he advocated only for larger entrances, of 80 feet width or more.

At the end of a major work he himself frequently thought that he would like to undertake it again in the light of the first experience. In the case of the work described in the Paper, however, there was nothing that he would like to alter, except that perhaps those concerned might have been pressed a little more strongly to have the West Waterloo dock and the Victoria dock dry during the operations. That would have obviated much tedious work, with a consequent saving in time and expense: the gates could have been built in the dry. Being of such abnormal depth, it was only in the Gladstone dock that the intermediate gates could be up-ended. The inner and outer gates had been up-ended in the lock without difficulty.

**Mr D. G. Braid** said that it would be noted that considerable dredging had taken place not only in the fairway but also in the dock. This dredging was carried out mainly by ladder bucket-dredgers, but during the latter stages of the work it was found that the areas which had previously been excavated to dredged level (the area along the river approach wall, which was excavated under cover of dams, and the area immediately in front of the emergency sill, which was excavated under cover of the

south closing dam) were fouled with substantial pieces of rocks. Where they had come from was open to discussion: it might be possible that, as the dredgers reached the dredged cut at the river approach wall, a surge of the dredger had dislodged pieces of rock. There was obviously similar danger in the case of the area immediately south of the sill.

He believed that it was possible, with the ladder bucket-dredger, to dredge close up to a river wall. The dredgers available for the work in question had been the *Lyster* and the *Vulcan*. The *Lyster* had a rather short ladder, whilst the *Vulcan* had a longer ladder and could dredge ahead of the bow. It was not possible, however, owing to the tide, to dredge at right-angles to the river approach wall. An effort was made to operate the dredger in such a way that it removed the broken rock, but that could not be done, and resort was therefore had to grab hoppers fitted with special buckets. At first an all-welded tine bucket fitted with teeth was used, the size of which was about 6 feet 6 inches, or 7 feet when open. It was intended to drop the buckets on top of the stones, which ranged up to about 2 cubic yards in size and were of various shapes—in general, rather flat. Unfortunately, the tine buckets tended to tilt over when landing, since the rocks formed a fillet to the river approach wall. Orange-peel buckets were therefore tried, it being hoped that one of the leaves would jam when lowered, so that it would be possible to obtain a good grip. They were not as successful as the tine buckets, however, so the latter were again used. In the area immediately south of the emergency sill some of the stones interlocked and jammed tight; explosives were used to dislodge and spread them, and they were eventually cleared. Similar trouble was experienced in the dock: after the main dredging had been completed, some stones, curiously enough, were found over the area of the dock. That was not due to blasting: he thought that perhaps it was due to the dredgers keeping stones in front of them as they progressed across the dock. The difficulty lay not in the number of stones but in locating them. They were swept up and buoyed, and the grab hopper was then used to pick them up.

With regard to the construction of the invert, the Author had stated that the excavation was taken down to sill-level and that thereafter it was carried out in alternate transverse bays. It had been felt that, although it might not be necessary to adopt that procedure, it would be better to take the precaution of not removing all support from the toes of the dock walls. It was obvious that there would be a saving in shuttering, but Mr Braid thought that the main object was to leave some support for the walls.

Since the invert was designed as an arch, it was necessary to reduce to the minimum the shrinkage of the concrete. That was one reason why each strip was dealt with in three sections (the crown first and then the haunches). In addition, he had suggested that the work should be done in that way because he did not think that a true profile could be obtained

if the filled bay was concreted in one operation ; he was not sure about that, however, since he had read certain Papers which appeared to indicate the contrary.

His last point was in connexion with the Bramley-Moore culvert. The Author had stated that that was an experiment in constructing a trench with an excavator. Mr Braid agreed that it was an experiment in one sense, but he did not think that permission would have been obtained from the Engineer-in-Chief merely to conduct an experiment without other good reasons for the procedure.

A further reason for the use of a high-modulus sheet-pile was that it was essential that no subsidence took place in this region, where there was a large quantity of machinery foundations.

The excavator was perhaps not the best machine that could have been used : a type of machine existed on which the loading boom was the only moving part, the cab remaining stationary. With the normal excavator in use, the restricted width of the trench entailed posting men on either side of the excavator to clean the trench. The same method was being tested in the new passage in the Langton-Canada-basin scheme, where there were wider trenches, and had so far proved successful.

Mr G. L. Hargreaves observed that the Author had packed his Paper with detail : that was desirable, since engineers were inclined to agree on principles and to differ, often to a considerable extent, on points of detail.

Mr Hargreaves proposed to confine his remarks to the gates and their housings and to the concrete work. With regard to the gates, his questions might be elementary, since he had had no experience of mitre-gates.

A mitre-gate, when under water pressure, must distribute its load between the hollow quoin and the sill, and, if the gate were to be watertight, the pressure must obviously be distributed fairly evenly between the mitre faces of the quoin and the clapping faces of the sill. Could the Author give a little more information on the measures taken to ensure that those state of affairs was attained ? The Author had mentioned that the gates were held slightly off the sill and that a saw was passed between the mitre-posts ; Mr Hargreaves did not understand the procedure or the purpose of it, and would be glad if the Author could clarify that point. He gathered that there would be a small clearance between the heel-post and the hollow quoin when the gate was free to move, and, when pressure came on the gate, the heel-post would have some small freedom of movement in order to embed itself in the quoin. According to the illustrations, there seemed to be room for such movement on the bottom pintle, but what occurred at the top was not clear. The top pintle was housed in a roller-bearing, and he wondered whether some provision was made for the bearing as a whole to move slightly in a transverse direction.

The hollow-quin masonry, apparently, was left about  $\frac{1}{2}$  inch proud and was trimmed to its final shape and alignment after the whole wall had been completed. This wall was founded on rock, and it would not

normally be expected that appreciable settlement would take place. He wondered, however, whether the Author had taken observations to discover whether there had been any distortion in the fabric of the wall through hardening or settlement or any other cause, and whether the  $\frac{1}{2}$ -inch allowance had been found to be adequate.

The space devoted in the Paper to the concrete work, compared with the space given to certain of the temporary work, such as the cofferdams, seemed very small, and Mr Hargreaves had obtained the impression that more attention had been given to the construction of the temporary work than to the final permanent work. For example, the aggregate used throughout appeared to be an all-in aggregate, which he understood to be aggregate ballast as taken from the pit, no attempt being made at artificially grading or designing the mix. He could appreciate that that was satisfactory for the wall as a unit, because, as the Author had stressed, density was desired rather than strength, but it might have been a good investment to take more care with the face work: not very long ago jobs of the kind in question had been done almost entirely in granite masonry, at very considerable cost. Moreover, any maintenance required in the future would be very expensive indeed. Had that point been considered and were there any overriding considerations leading to the decision to use ordinary ballast aggregate for all purposes, including the faces?

The last matter on which Mr Hargreaves wished to have information was the decision to omit expansion or contraction joints in the dock walls. It had already been mentioned in the Discussion that such joints were made in the invert, because it was suspected that they would enable some part of the invert to set and contract before the rest was placed; and he would have expected that a similar provision would be made in the walls. The Author had mentioned that certain movement had occurred and had been apparently localized at the construction joints; but was there any particular reason for omitting provision for contraction or expansion?

**Mr R. N. Norfolk** said that the most unusual achievement described in the Paper was, in his opinion, the flotation of the bascule bridge from the Waterloo-Victoria passage to the Victoria-Trafalgar passage.

The centre of gravity of the bridge was moved to 23 feet 3 inches forward of the gudgeon pin by the removal of the quadrant plates and the concrete ballast from the ballast-box and by the disposition of 20 tons of kentledge at the nose end of the bridge itself. The bridge was then jacked forward 23 feet to bring the new centre of gravity of the bridge over the centre of buoyancy of the two lifting-camels. It would be noted that the camels were of unequal capacity, thus requiring a careful programme of pumping to ensure that an even lift was given to the bridge.

The arrangement of the bridge on the camels was far more stable than it appeared to be at first sight. The weight of the bridge had been reduced from about 680 tons to 300 tons by the removal of the ballast and quadrant plates, but the weight of the camels and the water ballast was as much as

1,050 tons. That resulted in a combined centre of gravity about 2 feet above the water-line, giving a calculated metacentric height (GM) of 23 feet.

The entire operation, from the commencement of pumping to the time when the bridge was lowered on to its launching brackets at the new site, took  $5\frac{1}{2}$  hours—1 hour less than the scheduled time.

In his introductory remarks the Author had referred to shoaling in the area of slack water at the entrance to the lock. Mr Norfolk did not think that that was very surprising when the high silt charge found in the Mersey was considered, and he thought that special provision should be made in the design of such locks to deal specifically with shoaling on the outer sill. The existing sluicing-culverts in the approach wall did not, he thought, go right into the mouth of the entrance, and the provision of a single flushing-culvert over the top of the sill might have overcome the shoaling. That would, of course, have involved the installation of an extra set of paddle machinery, since otherwise it would not have been possible to dry out the lock under cover of the emergency gates.

The Author had also mentioned jet-eroders in connexion with the removal of silt: perhaps they might have been used in the entrance to the lock to overcome shoaling. Had the Author any special recommendation for dealing with that trouble, and did he agree that shoaling should be anticipated and special provision be made for it?

Mr D. H. Little asked whether it was the general practice at Liverpool to dress masonry to  $\pm 0.015$  inch: he understood that  $\pm 0.004$  inch was a more general figure for the large caissons, and he had been told that the greenheart of the caissons themselves was dressed to  $\pm 0.002$  inch. To what accuracy were the sliding-ways dressed, and how were the paddles dealt with?

At Singapore the main valves were of the paddle type, and he believed that the masonry there had been given a very high polish at the works and dispatched in that condition, and had been accurately fixed on site without further polishing.

He wished to know whether, in the work described in the Paper, the masonry had been bolted back to the concrete in any way, and whether granite was normally used for copings at Liverpool.

Reference had been made in the Paper to the fact that one of the major walls was made a little higher than the other, in order to act as an anchor for a windscreen. Was that windscreen intended to be merely a local protection or was it to be a protection at a distance? If the latter were the case, had any models been made to show what protection was likely to be afforded by the screen?

He considered that the design stress of the arch of 750 lb. per square inch was rather high. Had consideration been given to the possibility of venting the floor instead of demanding that it withstand the hydraulic pressure?

Cracking had been referred to as taking place at the construction joints : was that new cracking or merely the opening of the joints themselves ? He himself generally employed vertical construction joints and incorporated shear devices to check the joints, including a bitumen filling to keep out the water.

With regard to the steel sheet-piling, he noticed that reference was made to the fact that universal-joist piling was used in preference to cranked piling because it was stiffer. His own experience of sheet-piling had never led him to believe that the steel joists were stiffer than cranked sections, and he did not consider that they were quite as watertight as the cranked sections.

What penetration had been attained in the rather strong rock ? Such rock as he had encountered had not been so strong as the rock at Liverpool appeared to be, and he had attained a penetration of only 4-5 feet at the most.

He agreed with the Author that high-strength concrete was not needed in dock work, and he thought that the proportions of 1 : 8 were quite satisfactory.

He was interested to learn that no special facing concrete had been used on the faces of the walls. What kind of surface had been obtained ? Did the rather large stones, up to 9 inches in size, have any undesirable effect on the appearance of the surface ?

He noticed that as much as 105 lb. of explosive had been used at a time. He himself had used up to 150 lb. in blasting concrete under water. For above-water work he had used steel-wire torpedo nets to counter flying debris, and would have considered that the Author's hemp nets would not wear very well.

There was a reference in the Paper to the use of blue bricks for the lining of the subway under the lock : was there any advantage in their use ? He himself would have been satisfied with plain concrete.

**Mr Cecil Peel** asked why a swinging foot-bridge had been provided over the lock as the means of communication, in preference to the usual footways on the gates. Was it for speed in working ships through the lock, and to avoid the nuisance of having to drop the guard chains and stanchions ? At the Port of London the use of foot-bridges over lock entrances had been discontinued some time ago.

Had any trouble been experienced with any of the dams, which appeared to have had a very small seal into the rock and the overlying material ? Had there been any signs of lateral swaying and collapse ?

With regard to the pipe subway underneath the lock, he considered that the lead sealing ring that had been placed in the joint between the wall and the floor was an excellent feature, since the relative vertical movement that usually occurred at that point led to cracking that was difficult to deal with later.

Cornish granite had apparently been used for the sluice facings : had

the Author always found that material satisfactory? There had been occasions when it had been inclined to disintegrate under such conditions.

With regard to the lock gates, would not it have been preferable to make them a little wider and so to reduce the maximum preponderating weight of 96 tons, which, for such comparatively narrow gates, seemed to be a high figure?

The provision of numerous large scupper-holes in the gates was a desirable feature. Gates were frequently made with small scupper-holes that became choked with mud and sometimes did not perform their function. It appeared that the scupper-holes were placed on the outer face of the gates and not on the inner face. Why was that done? It seemed to him that it was always better under low-tide conditions, when the lock was full, to have a dead weight of water in the gate to counteract the increased buoyancy, rather than to rely upon the friction of the hollow quoins to resist the uplift.

Had the possibility been considered of utilizing welding in the gates, in preference to riveting?

**Mr E. I. Loewy** said that he had recently been connected with work on a lock about two-thirds of the size of that described in the Paper and not as much as two-thirds as deep; after much discussion, it had been decided to make the culverts as large as those described in the Paper. He would, therefore, be interested to know what criteria had been used in determining the sizes of those culverts. No doubt locking-time was taken into consideration, but he wondered whether the question of slope of the water surface and the possibility of the movement of ships had entered into the calculations, particularly since the culverts occurred only round each gate and did not extend along the length of the lock with individual outlets all the way down.

The culverts described in the Paper were all at a very low level, being fairly uniformly at invert-level, and he wondered what provision had been made for maintenance work on the paddles. Was there some special means of placing limpet dams on the mouths of the culverts, so that maintenance work could be carried out without employing divers?

A further point that interested him was that there were no fenders down the body of the lock. Was that the general policy at Liverpool? In one case, to his knowledge, there had been considerable argument about the provision of fenders, and in the end it had been decided to instal a number of fenders along the whole length of the lock, and the arrangements for fixing them had caused much trouble.

**Mr J. S. S. Ramsay** said that he presumed that, in moving the bridge, the Author had had the advantage of a fixed level of water and had not had to cope with current or the rise and fall of tides.

With regard to the 300 tons of ballast that had been removed from the bridge, it would have been an advantage if the ballast had consisted of convenient blocks of cast iron, but it was fortunate that it was ordinary

plain concrete and not burr-concrete consisting of cast-iron borings, cement, and sand, and weighing about 330 lb. per cubic foot.

He would like to know how the track girders were dealt with : if the bridge was moved off the track girders, were they lifted and then re-set in the new position before the bridge was off-loaded in that position ? The setting of track girders was not a simple matter, and took some time to accomplish with the accuracy necessary for the satisfactory working of the bridge.

With regard to the gates, reference had already been made to the corbel over the gate recess, which formed a satisfactory finish but which had a disadvantage in connexion with the placing of the gates and also with possible future unstepping. The latter event occurred only once in a lifetime, however, and was not a matter of major importance ; but the arrangement prevented the gate from being used as an access across the lock and necessitated the provision of a foot-bridge.

Reference had also been made in the Discussion to fendering in the lock. There was a very elaborate and rather costly arrangement of fendering on the gates, consisting of five lines of American elm vertically and about fourteen lines of greenheart horizontally. Why had greenheart and American elm been chosen ? He presumed that, since the fendering was on only one side of the gates, it was intended to protect the gates when they were in the recess, and he supposed that that large quantity of fendering on the gates, which were 18 inches inside the face of the dock wall and the coping, was due to bitter experience of the damage that ships could inflict on gates. He had recently seen some gates about 100 feet wide on a sea-front entrance to a dry dock ; there was only one horizontal fender on the gates. He had looked closely for signs of the gates having been damaged or abused, and had found none, although the gates had been in position for between 10 and 20 years. In the present conditions of high cost and scarcity of timber and labour, would it be taking an undue risk to modify the arrangement of fendering to, say, six lines of horizontal fendering ?

Mr Hargreaves had referred to the saw-cut made down the mitre-posts of the gates. That was a very common and satisfactory course to adopt when mitre gates were placed in the dry, as the intermediate gates had been in the work in question, but it was more difficult when they were placed in the wet, as the inner and outer gates had been : those gates had not been saw-cut. Templets had been made after the granite dressing was finished. It was a tribute to the accuracy of the dressing of the granite that the same templets had been used without alteration for all three pairs of gates.

With regard to the vexed question of painting, the gates in question had been given four coats of neutralized tar. What was the expectation of life of that protective coating and how it would compare with the more expensive brands of paint ?

\* \* **Mr Harry Ridehalgh** observed that the Mersey Docks and Harbour

\* \* This contribution was received in writing.—SEC. I.C.E.

Board were particularly well placed to carry out their own works by direct labour by reason of the excellent organization that they had built up over many years to deal with such specialized types of works as that described in the Paper.

It had, however, been his experience on most direct-labour works that there was a tendency to commence operations on the site without first preparing a sufficiently complete and detailed programme, undue reliance being placed on the freedom permitted by that method of execution, to vary the details and order of construction, materials, and methods employed, and possibly the extent of the project, as circumstances arose, with the knowledge that there was invariably the great advantage of freedom from working to a completion date.

Consequently, work progressed unhurriedly until some Committee, dissatisfied by monthly excuses for delay, asserted its authority and called for completion "with the utmost despatch"—but still without naming a completion date.

It was not Mr Ridehalgh's intention to suggest that that was the spirit under which the works described were carried out, but it was noticed that a period of  $11\frac{1}{2}$  years elapsed from commencement to completion, during which work was suspended for  $3\frac{1}{2}$  years, leaving 8 years for actual construction. He did not think that any contractor could have afforded to take so long for a contract valued at, say, £1,300,000 excluding gates; he felt sure that, had the work in fact been carried out by contract in that instance, the Board would have been able to enjoy the benefits of the new entrance some years earlier, with consequent saving in capital cost and gains in revenue.

Furthermore, it was difficult to imagine an initial plan which involved the construction of forty-five cofferdams, ingenious as many of them were, and it was possible that the adoption of special measures such as a specially designed form of full-tide dam, capable of safely withstanding storm conditions, might have proved cheaper. Working under semi-tidal conditions caused inevitable delays and, over a period of 8 years, the time and money spent on pumping down, moving pumping equipment, sluicing down, restricting concreting, and so on, was doubtless considerable.

The planning of the lay-out was good, and it was interesting to note that the angle made by the entrance with the river had not led to any serious difficulties during locking-in and locking-out, due to current effects at the entrance. It would be interesting to know whether consideration was given to building a model to study those conditions and to ensure that the best possible angle was, in fact, selected. Entry into a dock from a tidal river was always a very complex problem.

It appeared from Mr Ridehalgh's knowledge of conditions that building the dock walls as high as 9 feet above the highest predicted water-level might have proved to be an uneconomical method of overcoming the belting problem, and he wondered whether the cope could have been set 4 or 5 feet

lower if a few vertical fenders had been provided. By that method the height of the walls, and consequently their thickness also, could have been reduced. A further saving seemed also to have been possible by the reduction of the wall section below rock-level (the bearing capacity of the rock being described as good). Again, he wondered whether it would not have been possible to eliminate the concrete lining to the invert between the gates. Special measures, which must have been expensive, had been taken to excavate for and concrete this area. The chief objection appeared to be the possibility of leakage through rock fissures, which could, perhaps, have been overcome by grouting.

From a perusal of the concreting data, Mr Ridehalgh could not help but feel that that part of the work had not been treated with the respect it deserved. Over-sanding, high water/cement ratios, and segregation by dropping from great heights, all referred to in the Paper, had no doubt contributed to the very variable test results remarked upon. Having seen bad concrete produced even under conditions of the most rigid control, he found it difficult to be satisfied that consistently good concrete could result from the procedure described.

Had it been found necessary from the Author's experience at Liverpool to provide granite copes? Since no fenders were indicated, it was assumed that the cope suffered more than it would do in the case of a fendered wall, and granite might have been used for that reason. It appeared, however, to be a luxury to dress the top surface to a fall of  $\frac{1}{4}$  inch to 1 foot, having regard to the present high cost of such special labour. Also, was it found to be better to have the bollards set back from the cope rather than along it.

The use of sheet lead for forming watertight joints was referred to in the Paper; Mr Ridehalgh's own experience was that lead became brittle with time and fractured, whilst copper, on the other hand, remained ductile.

Mr. Ridehalgh's firm was carrying out experiments to ascertain the best disposition and shape for the outlets of lock culverts discharging into confined areas and, although it was noted that in the case under discussion there was at all times more than 10 feet of water over the top of the culverts in the inner compartment, it would be valuable to know what effects were experienced by a small vessel locking up when the culverts were discharged under full head into that compartment from the dock. Instances had come to his notice in which the shore ropes of small vessels had parted as a result of undue turbulence and surge.

**The Author**, in reply, said that he was pleased to have some of his own views confirmed by Mr Leighton, particularly with regard to the depth of entrances for ocean-going ships. It was, in fact, the intention that the new Langton river-entrance, now under construction on the site of Canada basin, should not be used for more than 4 hours on either side of high water. The caissons were being designed to operate at low water of spring tides, however, so that, in an emergency, smaller vessels could use

the lock down to low water, when there would be a depth of 19 feet on the sills. Water could not be lost indiscriminately, because the system was impounded to the high-water-level of ordinary spring tides and, except for a few days over each period of equinoctial spring tides, every gallon of water that escaped had to be replaced by pumping.

Mr Braid had referred to the difficulty of working the dredgers against the river approach wall; the Board's bucket-dredgers were all of the centre-ladder type, and no doubt the now obsolete side-ladder dredger would have been of assistance in that particular case.

It had been a wise precaution to concrete the invert in sections; otherwise, cracks due to setting-shrinkage would almost certainly have occurred. The fear of the possibility of not obtaining a true profile was probably justified, also; the mix used was as dry as could be economically produced by the mixers on the job, which had all been of the fixed-horizontal-axis type. Perhaps drier mixes could have been produced by a different type of mixer.

With reference to the mitre-gates, Mr Hargreaves had inquired about the distribution of pressure between the hollow quoin and the sill. Each deck of the gates had been designed as one member of a three-pin arch loaded by an appropriate zone of pressure, the hollow quoins acting as the abutments and the mitre as the centre-pin. The effect of the support given to the bottom deck by the sill had been ignored in determining the scantlings of that deck. Under load, the tendency of the deck to shorten axially under the heavy arch-thrust, and thus for the arch to flatten, ensured that more than ample pressure was maintained against the face of the sill for watertightness; the pressure transmitted by the heel-post to the hollow quoin was even greater. Leakage past the meeting faces of new installations could usually be attributed to faulty joints in the masonry or to obstructions, with chafing and wear as an additional cause in the case of old gates.

The object of the saw-cut down the mitre-posts was to ensure intimate contact at every point; it constituted the final dressing in situ. The gates were held slightly off the sill so that the final length of the gates should not be short by the width of the cut, which had been effected by a hand saw. The Waterloo lock gates had been constructed in a horizontal position and a considerable time had elapsed before they were due for stepping. During that time slight warping had occurred. In the case of the intermediate gates the mitre-posts were trued by the saw-cut, but, as Mr Ramsay had pointed out, the final dressing of the other pairs of gates had been to a templet before stepping in the wet, thus avoiding the necessity for making a saw-cut under difficulties. The inner gates had been put to the test of having a full head on the back while the lock was dry, and no weeping had occurred.

The pintle bearing was set coaxially with the heel-post and hollow quoin, the shape of the bearing giving the degree of freedom required to

take up wear. In a fully suspended gate, the horizontal reaction at the bottom of the heel-post, forming the lower force of the fixing couple, was taken directly on the hollow quoin; the lower end of the heel-post remained, therefore, in intimate contact with the hollow quoin whether pressure was on the gate or not. There was practically no play in the collar-strap bearings, but coupling-screws had been provided in the anchorages to allow for initial adjustment and wear, although very little wear was to be expected at the top of the heel-post, where the weight of the gate tended to pull the heel-post away from the hollow quoin.

The  $\frac{1}{2}$ -inch dressing allowance left on the hollow quoin had proved ample for its primary purpose of catering for slight imperfections in the initial dressing and placing of the stones and in setting-out. The question of provision for movement of the wall hardly arose, since any movement was likely to be inwards, towards the centre of the lock. Observations had been taken on the walls and no movement had been discernible. The east and west intermediate hollow quoins had been built monolithically into their respective walls in deep trenches, and it had not been possible to tape directly across the lock until the dumpling had been excavated. In the case of the inner and outer positions, only one hollow quoin had been set with the concrete, a pocket having been left to accommodate the masonry of the other, which had been fixed at a later stage after the dumpling had been excavated. Although some risk might have been involved in the indirect setting-out, the method adopted for the intermediate quoins was considered the more satisfactory.

Mr Hargreaves appeared to be under the impression that insufficient care had been taken with the concrete, but that had not been the case. As Mr Leighton had pointed out, those concerned had had a great deal of experience in that class of work. In addition to the two river-entrances mentioned by him, recent construction at the port had included the Gladstone wet and dry docks, Bidston dock, and the modernization of the Trafalgar dock area. The work had been done by direct labour in each case, and key men moved from one job to the next carrying with them accumulated experience. The concrete produced was satisfactory in use, and both Mr Hargreaves and Mr Little would be interested to know that, although some scoring had occurred on the walls of the Gladstone river-entrance, no damage requiring attention had yet been done by abrasion of the face of any of the walls on the works mentioned. A good surface was obtained by tamping the concrete particularly carefully against the face-shutters, and the presence of rather large stones close to the face did not appear to be detrimental in any way. The decision to use all-in aggregate, alternatively known as ballast, was made purely on grounds of cost.

Mr Hargreaves had coupled a reference to the omission of expansion or contraction joints in the dock walls with a reference to the provision of such joints in the invert. The joints in the invert, however, were in

reality ordinary construction joints, since no filler or seal had been provided to cater for relative movement between the sections after the concrete had set. Adjacent sections of wall had been concreted at much greater intervals of time than in the case of the invert, but, owing to their greater length, the setting-shrinkage had been sufficient to open the vertical construction joints in a number of cases. Mr Little's practice of providing a seal embedded in the concrete would have been of some advantage in the case of the lock walls since, in one instance, difficulty had been experienced in stopping the weeping which had occurred through a joint. The Author did not think that seals were necessary in the walls of wet docks where there was little fluctuation of the water-level, nor did he think that changes in temperature or moisture content played a significant part once the concrete had hardened.

Mr Norfolk had suggested that special provision should have been made for clearing silt from the emergency sill, and the Author agreed that the flow out of the lock when the inner compartment was being run down while the outer gates were open was not sufficient for the purpose. He considered that ordinary sluicing culverts were preferable to jet-eroders in that situation. Jet-eroders had been provided to sluice the inner gate-platform because there was no natural head available on the dock side of the inner gates; to overcome that, resort had been had to the expedient of using the hydraulic-pressure system, but the operation of the eroders strained the hydraulic system to its ultimate capacity, and more energy could be obtained in a short time by running, say, 1 foot of water off the dock by means of a suitable culvert.

With regard to Mr Little's reference to the standard of accuracy for dressing masonry, the Author agreed that  $\pm 0.004$  inch was a usual figure. In the case in question instructions had been given for the dressing to be done to that figure and, in general,  $\pm 0.005$  inch had actually been achieved. As an isolated case, one of the hollow quoins had shown depressions of up to 0.015 inch, perhaps due to local softness. It was desirable for the hollow quoins to be as true as possible to reduce wear to the minimum; the watertightness had not suffered, however, and there had been no weeping. The paddle-grove meeting-faces were dressed to  $\pm 0.004$  inch and the paddles had been fitted individually by placing them against the masonry in situ and dressing off the high spots.

No stones had been bolted to the concrete backing, which had been carefully placed. Granite copings had been normal practice at Liverpool up to the present time: no doubt use would still be made of granite for copings where wear by wire ropes was likely to occur, but the supply of granite would almost certainly be from the demolition of existing copings that were no longer required. Concrete copings had been used in a few recent instances for quay walls, and had so far proved satisfactory.

The windscreen was intended to be for local protection only. Wind-screens had been found necessary at the north end of the docks where the

situation was much more exposed; the Author doubted whether one would prove necessary at the Waterloo river-entrance.

Referring to the design of the invert, Mr Little had expressed the opinion that a design stress of 750 lb. per square inch was rather high for a design based on the usual assumptions for a masonry arch. In most circumstances the Author would agree, but the arch in question would have to withstand water pressure only, and the upper limit of the loading could, he thought, be forecast fairly closely; he considered that, with a good-quality concrete, there was sufficient margin.

Venting of the invert had been considered; there were a number of examples of it among the docks and passages at Liverpool, but it was not certain that the vents always performed their function. Water could be seen flowing from some of the pipes but not from others, and it was considered safer to provide an invert capable of withstanding the full uplift.

Mr Ridehalgh had suggested that the invert could have been dispensed with altogether: that form of construction had been adopted at the 100-foot wide river-entrance lock at Birkenhead, where the sandstone formation was similar to that encountered at the Waterloo river-entrance. So far as the Author was aware, no trouble had been experienced, but he believed that the lock had never been dried out. A certain deepening had occurred, owing to slow disintegration of the upper surface of the rock. It was considered, however, that the danger lay in the fissures, which, it was feared, might not be capable of being stopped effectively by grouting, since there might be unsuspected seams of more porous rock.

On the question of steel sheet-piling, the term "robust" used in the Paper was intended to signify ability to withstand hard driving and handling without distortion or buckling. The cranked sections were structurally stiffer, but the greater flexibility of the joists was considered to be an advantage for a timber-framed dam built under the conditions described.

On the site of the works "roach" was usually found overlying the hard rock in varying thicknesses up to about 4 feet. "Roach" was easily penetrated by piles, but, since the transition to hard rock was gradual, it was difficult to give any precise figure for possible penetration into the latter, although 18 inches might be mentioned as a rough guide. Excessive penetration of either, however, was to be avoided, since it tended to shatter both materials rather badly.

As Mr Little had suspected, the hemp nets used to counter flying debris from areas that were blasted did not wear very well, but they were easily repaired on the site.

Blue brick had been used to line the subway under the lock since it was considered that a higher degree of watertightness could thus be obtained, which was regarded as being of particular importance in that situation.

Mr Peel had wondered why a foot-bridge had been provided in prefer-

ence to a gangway over the gates : Mr Ramsay had mentioned the cleaner finish effected by corbelling over the gate-recesses, but there was also another reason. In normal operation, the Central docks were levelled with the river  $1\frac{1}{2}$ –2 hours before high water of each tide and the gates were hauled back into their recesses and remained there until high water. Without the foot-bridge, access across the lock would have been impossible during the whole of that period. The operating staff regretted that it had not been possible to place the bridge over the inner or outer gates and so to keep it in use while a ship occupied the full length of the lock.

No trouble had been experienced with any of the dams from lateral swaying once they had been completed : that could have occurred only in the case of box-dams where there was no adjacent masonry against which to shore. The danger of lateral swaying in a storm was one of the reasons which had led to the decision to avoid full-tide box-dams and to confine box-dams to the half-tide type.

Creetown granite had been used for the sluice facings, and, so far as the Author knew, Cornish granite had never been used for that purpose at Liverpool. He knew of no trouble with sluice facings of Creetown granite.

There would have been very little to gain from increasing the width of the gates to reduce the maximum preponderance. The machinery had been provided with ample power from other considerations, but there might have been a slight saving in wear at the lower end of the heel-post consequent upon the reduced reaction.

The position of the scupper holes accorded with usual practice at Liverpool, and there was no question of the safety of the gates at low tide with a full head on the back of the gates, since the frictional force required was very small compared with the magnitude of the thrust against the hollow quoin. The excess of the uplift on each gate over its dead weight was about 40 tons, and the total reaction at the hollow quoin was calculated to be about 2,000 tons.

At the time when the gates had been designed, welding had not been considered to be sufficiently reliable to be adopted.

In reply to Mr Loewy, the Author remarked that the size of the culverts had been based on locking time. The lack of multiple outlets extending along the full length of the lock was, perhaps, a slight disadvantage. The Gladstone 130-foot and Birkenhead 80-foot river-entrances had been provided with multiple outlets, and it was intended so to equip the new entrance into Langton dock. The question of turbulence and slope of water had not really entered into the calculations, in view of the experience gained in working other locks in the port. The paddles were equipped with tell-tales to indicate their position and, in levelling up with craft in the lock, the paddles were opened by stages to avoid undue turbulence. If a single craft were in the lock, it was tied up on one side and the paddle on that side was opened rather more than the one on the opposite side. The water passed under the ship and, rebounding

from the opposite wall, had the effect of pinning the vessel securely against the wall to which it was tied ; that technique enabled the lock to be filled more quickly than would be the case if both paddles were opened by the same amount. Mr Ridehalgh would be interested to know that it would be decidedly unsafe to open the paddles fully under a full head when locking up small craft ; the operation was never attempted.

Maintenance work on the paddles would not normally be done in situ, as envisaged by Mr Loewy. The stand-by paddle would be put into operation and the normal working paddle would be lifted out of position and the work done above ground. Experience showed that the necessity for such maintenance was very rare : in fact, the work would be in the nature of repairs rather than maintenance.

Up to the present time, it had been the general policy at Liverpool not to provide fenders on concrete or masonry walls. Practically all the vessels that used the Waterloo river-entrance were fitted with their own fenders in the form of belting, and it was felt that, if the ship was more likely to be damaged than the lock, those in charge on board would take greater care. Nevertheless, consideration had been given to the provision of some form of fender of the swinging or pendulum type fitted in the embayments of the river approach wall. Difficulty with the fixing arrangements had led to abandonment of the idea, however.

Mr Ramsay was correct in presuming that the bridge had been moved in still water. The water-level in the dock, however, had been intentionally lowered during the operation in order to assist in landing the bridge at the new site.

With regard to the removal of the track girders, perhaps the operation would have been clearer to Mr Ramsay if the Author had mentioned that, although the bridge was designed to span 70 feet, the old passage was only 60 feet wide, the top of the wall under the bridge having been finished with a shallow step to give clearance for the cross-girders. The sliding ways had been extended over the step on timber cribwork, making it possible to slide the bridge clear of the track girders. Ample time had been allowed between sliding the bridge forward and floating it across the dock for the removal and careful re-setting of the track girders in their new location.

With regard to the fendering on the gates, greenheart had been chosen on account of its hard surface and resistance to decay, and elm on account of its resilience and resistance to impact. The face of the fendering was only 3 inches inside the cope-line and not 18 inches, as supposed by Mr Ramsay.

It was necessary to provide sufficient fendering to give ample protection to the gates at all water-levels from high water to low water. The work had been carried out before the war, when timber was readily available and there was no inducement to leave anything to chance. No doubt the entrance to the dry dock to which Mr Ramsay had referred did not have

to deal with such a multiplicity of small craft as did the Waterloo river-entrance, and would be used only at high water. In view of the current shortage of timber, it was quite possible that in a new design the quantity of horizontal fendering might be halved, but only experience could justify the modification.

On the question of painting, it was difficult to be dogmatic ; but, when the gates of the Gladstone river-entrance lock, which had received the same treatment as that described in the Paper, were removed for repairs after being continuously in place for more than 15 years, it was found that the plating was in very good condition and that the coating of tar was still intact.

Mr Ridehalgh had referred to his own experiences on direct-labour works and suggested that a contractor might have completed the work a few years earlier than it had actually been finished. From the Author's own experience of contract jobs and the Board's new-works organization, he saw no reason to believe that a contractor would have been able more successfully to overcome the well-known difficulties of war-time and the immediate post-war period. Up to the outbreak of the war, work had progressed very favourably and according to programme. The Board had been fortunate, no doubt, in possessing a new-works staff imbued with the excellent tradition that they were expected to do any job entrusted to them well, quickly, and cheaply. Perhaps the corollary of Mr Ridehalgh's contention that a contractor could not have afforded to take so long for a job costing as much as the Waterloo river-entrance had actually cost under direct labour, should have been that the contractor would have had to charge the Board more.

Incidentally, it seemed paradoxical, but was nevertheless generally true, that the immediate effect of works of improvement of the type described was usually to reduce the Board's revenue. The new facilities enabled shipowners to effect the same number of sailings with fewer ships on which they paid dues ; but the shipowners and traders of the port, whose elected representatives were predominant on the Board, preferred to pay higher charges for a more efficient port.

In using the phrase " specially designed form of full-tide dam," Mr Ridehalgh presumably referred to a framed dam, possibly constructed in prefabricated sections for rapid erection. If so, the number of dams required would not have been materially reduced, and the danger of lateral swaying of the box-dams could still have been overcome only by means of heavy internal bracing and stabilizing banks of clay dumped on either side. The Author was very doubtful whether the work would have been executed any more cheaply than it had actually been done using half-tide dams. To a firm with the Board's experience in dam construction, the number of dams involved was not alarming. The number had deliberately been made large in order to reduce each dam to a convenient size from all aspects. The time spent in working under semi-tidal conditions with the

half-tide dams had been only  $4\frac{1}{2}$  years, and not 8 years as assumed by Mr Ridehalgh. The time spent on pumping down, cleaning off slurry, and so on, was never allowed to become excessive.

If Mr Ridehalgh meant to suggest the use of an embankment or some form of earth-hearted double-skin dam in the river, then the Author could not agree that it would have been cheaper than the method adopted; moreover, it would have been impossible to localize the serious consequences of a blow.

It had not been considered necessary to build a model to study current effects in the river, since it had been possible to draw upon a considerable body of practical experience with other entrances on the same side of the river. In any case, the choice of angle was limited and the class of vessel for which the lock had been designed was very manoeuvrable.

The coping-level had not been decided solely with reference to the belting problem. Experience at Liverpool showed that a minimum coping-level of +40 was necessary to prevent seas from coming over; that was only 1 foot lower than the height necessary to prevent trouble from belting. Any system of raised quay-edge fendering as high as that suggested by Mr Ridehalgh would have been an intolerable handicap to rope-running, and would have been a source of continual expense on repairs and maintenance.

The mooring-posts were set well back from the coping because the main deck on the larger ships using the lock was too high above coping-level for the quay-edge type to be used: had that type been installed, it would have been very difficult to keep the ships under proper control owing to the almost vertical inclination of the ropes.

The Author considered that granite copings were desirable for entrances and bullnoses for the reason he had given in reply to Mr. Little's remarks, although he would not expect much serious wear or damage to extend as high as the coping. Since the stones had been derived from existing copings on walls with battered faces, less dressing had been required to give the top surface a fall of  $\frac{1}{4}$  inch to 1 foot than would have been the case if a level surface had been provided.

As stated in the Paper, the walls had been designed in relation to previous practice. In a few cases trouble had been experienced with walls having a reduced section below rock-level, although the cause was not clear. Some method of keying or anchoring the wall might have been tried, but it was considered more prudent to eliminate all risk of inward movement.

On the question of the quality of the concrete, the Author referred Mr Ridehalgh to his remarks in reply to Mr Hargreaves. It was suspected that it was over-sanding that had made it possible to chute the concrete through considerable heights without serious segregation. The water/cement ratios were not high for the mixes used: precise determinations had not been made, but it was known that they were well over 0.5, above

which figure, as had been stated elsewhere, concrete was liable to deteriorate under the action of sea water. Mr Ridehalgh would recall that it had been stated in the Paper that, so far as the Author knew, the concrete produced by the technique described had not suffered under the action of sea water. Good concrete was not necessarily synonymous with high-strength concrete, or even with concrete giving consistent cube strengths. The only advantage to be derived from closer control would have been the possibility of adopting a leaner mix—say, of the proportions 1 : 10. In the Author's opinion, the saving in cement would have been more than offset by the extra expenditure necessary in other directions.

It was announced that the constitution of the Divisional Board for Session 1950-51 would be as follows :—

Appointed by the Council under Rules I(a) and I(b) of the Objects, Constitution, and Rules :—

Chairman : Mr. W. P. Shepherd-Barron  
Mr. G. Kenyon Bell  
Mr. J. Guthrie Brown  
Mr. Leopold Leighton  
Sir Arthur Whitaker  
Mr. A. Muir White

Elected by the members of the Division present at the Meeting, in accordance with Rules 10 to 14 :

Sir Claude Inglis  
Mr. J. H. Jellett  
Mr. D. H. Little  
Mr. John Palmer  
Mr. C. A. Wilson