Passage gates for Seaforth Dock, Liverpool

B. G. R. HOLLOWAY, M. J. FEIT & H. J. WADSWORTH

Messrs Holloway, Feit and Wadsworth

In § 35 of the Paper, filling between the hinge face plate and the hinge casting was referred to. This was provided because it was very difficult to fasten the hinge accurately to a concrete wall. The face plate was put in place first. A gap of about $\frac{1}{2}$ in. was left between the two and then gritted epoxy resin was poured down between them to fill the gap. We were rather afraid of doing this without some experimental testing, so we had a test rig built in the laboratory. It was about half the size of the actual job, and we tremmied the epoxy resin into this set-up through very thin pipes. We had some Perspex windows in the face shutter to see how it behaved, and to our satisfaction the gap filled up perfectly.

56. The rail bedding referred to in § 36 was done with a similar mixture and proved extremely effective; we examined the bedding 12 months or so after it had been in service and it appeared to be absolutely sound, with no signs of cracking up or deterioration of any sort.

57. The radial arms were fabricated allowing for a nominal gap of 1 in. at each end, and after site welding and adjustment of the walings the gaps at the hinge end were carefully measured and packings were machined to fit, tapered where necessary. It was found impracticable to repeat this procedure at the waling end owing to lack of flatness of the waling flanges, and the gaps were filled with an epoxy resin grout similar to that used between the hinges and face plates. The bolts holding the radial arms to the hinges and walings, together with the bolts in the other major connexions, were tensioned to predetermined loads to prevent opening of the joints under live load conditions.

58. In § 48 brief mention is made of troubles which have occurred with the bogie wheel bearings. These troubles have been the subject of considerable investigation and re-design and modifications to the bogies are now in hand. The original design is illustrated in Fig. 4 of the Paper. The design loading was compounded from the vertical load and a transverse frictional force at rail level limited by the 12·5% coefficient of friction of the articulation pin bearing bush. It was considered that any transverse tracking forces between wheel and rail could be neglected owing to the conical geometry adopted. The resulting maximum pressure on the Railko bearing material, taking into account the flexure of the shaft and the compressibility of the bearing material, gave a factor of safety of three on the ultimate compressive strength of the Railko.

59. It is estimated that the sector gates were operated about 2000 sequences during assembly, commissioning and in service, but in October 1972, rough and erratic running of the east gate was noticed and the gates were withdrawn from service. The bogies were removed and returned to the Contractor's works for dismantling and examination.

60. Of the total of eight bearings, in five the Railko material had disintegrated and the shafts worn to a depth of 10 mm in places. The remaining bearings were in fair condition but with some signs of distress in the Railko material.

61. Possible causes of failure were: (*a*) presence of silt in the bearing, (*b*) the fatigue effect of a rotating bush on a dead shaft, (*c*) the unsuitability of longitudinal lubrication grooves in a rotating bush, (*d*) long stationary periods during construction, (*e*) higher transverse forces than those allowed for.

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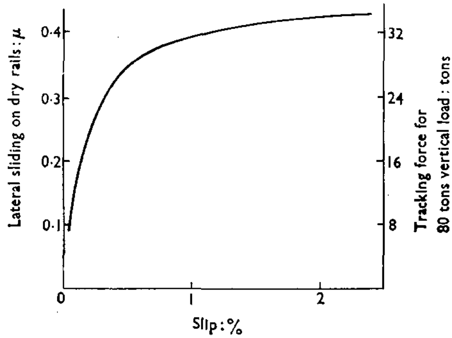

Fig. 9

62. Items (*b*), (*c*) and (*d*) are more or less constant factors to all the bearings and although they may well have had a contributory effect, the fact that three bearings were intact indicated that the cause must be a variable one. The ingress of silt as a cause of failure was also ruled out as tests showed it to be of very fine particle size and non-abrasive.

63. This left higher transverse forces as the most likely cause of failure. An investigation was made of information that had become available since 1969 and in a paper by Koffman[2] the curve shown in Fig. 9 was published, indicating the results of railway research on friction between wheel and rail. This relates the coefficient of friction to the angle of attack of the wheel relative to the rail. Fig. 9 indicates that, even with a small degree of misalignment, hitherto unsuspectedly high values of friction can occur, so that with only 0·6° of misalignment (i.e. within a reasonable manufacturing tolerance) a lateral force of over three times that assumed could have arisen, which would be sufficient to cause the failure of the five bearings and could account for the survival of the remaining three.

64. After considerable discussion a solution was proposed involving the use of a live shaft in two outboard bearings, permitting lower bearing pressures through increased bearing areas, better lubrication conditions than obtainable with a fixed shaft and rotating bush, the ability to accept high lateral loadings between wheel tread and rail while keeping bearing loads well within acceptable limits, and a shaft diameter which permits re-use of the existing wheels and bogie frames.

65. Railko has been retained as a bearing material in conjunction with new EN57 stainless steel shafts, but with the shafts sleeved with hard stainless steel to give a surface suitable for use with phosphor bronze bushes if desired.

66. Because of the necessity of hanging the guard gate on to a hinge with top and bottom pins simultaneously, it had to be balanced in a horizontal plane from end to end, and in a more or less vertical plane while being scuttled between timber guides. In order to ensure a direct perpendicular pull to the gate, regardless of the draft of the gate, sheaves were arranged to take the winch ropes to a lightweight pulley which ran up and down a vertical runway beam fixed to the back of the gate. As the draft of the gate deepened, the trolley rose up the runway maintaining a horizontal pull.

Mr M. S. A. Wilson, Greater London Council, formerly Rendel, Palmer and Tritton

I was engaged on investigation and preliminary design of the sector gates, together with the supervision of the model testing. I should like to make a few comments on the preliminary stages of the sector gate design.

68. There were many sector gates in existence before this job started, but there

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seem to be almost as many different types of sector gate as there are gates themselves. There are gates operating in tension, gates in compression, some with circular skin plates, some with straight skin plates, some supported on rollers and some merely hung at the hinge end. This meant that the design had to be based almost entirely on theory without our being able to look at comparable gates which bore out our theory.

69. In addition to the problems of size, these gates had to be capable of withstanding their full designed head difference from either side. Most other gates seem to be designed so that they have a full operating head from one side and a considerably lesser head operating from the other side. For instance, at St Malo there is a gate designed to withstand a fairly large head between high water and low water, with an occasional load from the opposite side when there is an exceptionally high tide.

70. As a result, one of the main factors that emerged from the theoretical studies was the significance of movements and deflexions of the gates under load. This had a considerable bearing on determining many of the basic design principles and dimensions. Among the items which were significantly affected by movements under stress were the vertical positions of the main frames, the radius of the gates themselves, the layout of the seals and the type of machinery adopted, as well as the decision to support the gates on rollers, which was at least partially influenced by possible difficulties at the bottom seal if they were entirely hung at the hinges.

71. The machinery arrangement finally adopted was that envisaged during the earliest studies. It is similar in concept to that in use at St Malo, although it is different from arrangements that have been more common in more recent gates. Various other arrangements were considered in the early stages of design in order to minimize possible maintenance difficulties and also because of the possible difficulties arising from the adoption of wire rope, which would be liable to stretch, and it was feared that there might be some difficulties in getting the precise positioning of the gates. None of the alternatives was considered satisfactory after detailed investigation, and I should like to ask the Authors whether there have been any difficulties in positioning the gates accurately, particularly during the stepped opening, as a result of stretch in the wire ropes.

72. Since sector gates are not common, most are tested, and the Americans seem to be thorough in their reporting and publishing of reports. This helped in anticipating the general results of the tests and thus in preparing the test programme for the model testing. The tests soon confirmed that the most important factor affecting the hydrodynamic effects with the general gate layout adopted was the shape of the central gap between the gates. The actual shape of the structure itself had little bearing on the forces and hydrodynamics.

73. The model tests were carried out before the final detailed design, and the final layout of the steelwork behind the skin plate is considerably different from that envisaged at the time the model tests were carried out. The model tests indicated that these changes in the main steelwork were unlikely to cause significant hydraulic difficulties or changes in the results of the test. However, the design of the centre seal was changed from the symmetrical layout originally intended to an asymmetrical layout, for reasons connected with achieving a satisfactory seal. Seals have tended to be a source of trouble in sector gates, from the point of view of both leakage and vibration.

74. I should like to ask the Authors whether the adoption of an asymmetric centre seal has resulted in any difficulties in regard to flow between the gates. Second, has it proved possible to carry out any full-scale trials to verify the model test results, as regards both flow patterns and hydrodynamic forces? Third, have there been any unforeseen hydrodynamic effects in the full-size gates themselves?

75. The Authors stated that it proved impractical to determine from model tests whether disturbance would be caused to shipping in Gladstone Dock during the

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levelling-up operation when large volumes of water would pass between the gates. Has any trouble been experienced in practice from this cause when the levelling operations have been taking place?

Mr N. O. Taylor, Rendel, Palmer and Tritton

I was a representative for the civil works at the site and also for the assembly of the sector gate and the other installations.

77. My site staff was concerned largely with the sector gates' assembly, since the guard gate arrived as an almost completed structure, and the site inspection was almost entirely the work of one inspector, one engineer (who was part-time), and myself, part-time.

78. The guard gate lower pintle and upper bearing were set to the northern sill and quoins, while the sector gates were related to brass plates drilled to mark the true centres of the sector gate hinges and set into the -20 ft LBD pasage floor. These points also served as two of the civil works setting out points.

79. The civil works contractor had set the 20 ton hinge face plates to $\frac{1}{16}$ in. of true position relative to the setting out points, using hydraulic jacks in conjunction with $1\frac{1}{4}$ in. British Standard Whitworth (BSW) bolts used to follow up the jack movement and to take the load. The plates were held back at the lower edge by the bottom row of Macalloy ties and at the top by adjustable temporary ties and struts. Twelve inches of concrete were poured and after checking the plate location concreting was completed in two 9 ft lifts. These pours comprised the concrete within the tapered plug in addition to that outside the diaphragm wall cell.

80. The east gate fixed hinge castings were handled by a Pennine MK 11 standing immediately over the hinge foundation, landed on to packings and jacks and to a jacking beam previously bolted on to the lower edge of the face plate. The casting was then held firmly against packs by service bolts into the face plate, roughly positioned and followed by the upper half. The two parts were bolted together by the fitted bolts and the whole fixed hinge (which had been pre-assembled and bored in line in the assembly shops) accurately set using the Taylor Hobson optical plummet positioned over the centre point on a light cantilevered platform. The engineer using the plummet was supported on a second staging independent of the other to avoid throwing the plummet out of line.

81. After setting and tightening against packs using the hinge foundation bolts, the location was jointly checked with the Contractor's Engineer to ensure that the four bearings fell within a vertical cylinder of 0·015 in. dia. This was carried out using a machined disc with a central register placed into each bearing in turn.

82. The process was repeated until the required accuracy was achieved. The method was repeated for the upper hinge with the additional check that all eight bearings fell within a vertical cylinder of 0·025 in. dia.

83. The necessity for such accurate checking was queried more than once, but if the design tolerances are faithfully carried out in the field, should some misfortune occur, it is as well for the inspecting engineer to know that at least the basic supports and swivels bear the correct interrelationship.

84. The gap between hinge castings and face plate—a nominal $\frac{1}{2}$ in.—was fully grouted using the sand filled epoxy resin material. This grout is extremely searching and it was found necessary to use a continuous run of steel strip seam welded to both casting and face plate. In view of some obstructions, including the jacking beam which made a 100% seal difficult, the lower 18 in. were poured first and allowed to set before completing to full height.

85. As the hinge installation progressed, the assembly of the gate lower quadrant proceeded from the sector rails with the two halves of the lower waling supported by the two bogies and the two radial arms. The best location of the outer flanges of the waling was obtained, checking by taping from the hinge centreline to reference marks on the waling outer flange, and plumb lines to check the lower flange from the upper.

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86. When assembly was complete, the nominal 1 in. clearance gaps at the hinge end of the radial arms were measured and steel packing plates were made to suit. At the outer end of the radial arms, sand filled epoxy resin was used as a packing since the arms abutted against the mill-finished flange of the walings.

87. All parts arrived with factory applied three coat bitumen/epoxy paint—apart from machined surfaces and weld areas. The latter, after suitable preparation by grit blasting, were site painted.

88. The three vertical seals were of greenheart timber and rubber sealing strip, the timbers being profiled to the concrete side seal faces and centre steel face before final fixing in their recesses.

89. After initial flooding of the dock and before demolition of the cofferdam, the gates were tested to the fullest possible head differential in both tension and compression conditions with the stresses analysed using the results of the comprehensive disposition of strain gauges applied for this purpose. The water was prevented from flowing beneath the gates by the use of tapered rubber strips inserted into the service gap, on the south side in the dry prior to flooding, and in turn on the north side by diver.

90. By comparison, the setting of the guard gate hinge post was simple. However, the effectiveness of the gate largely depended on the accurate setting of the sill and quoins. The precast sill blocks were set to within 0·01 in. of a vertical plane, using a stretched piano wire and internal micrometer together with a steel square and engineer's spirit level. The use of two wires was the original method but in view of the simplicity of using one wire the two-wire system was abandoned. Each block was supported on three jacking bolts and was restrained and adjusted in and out at the top by rigging screws. By these controls accurate line and verticality of placement was possible, before bolting down and dry concrete packing. The quoins were set using two vertical datum wires. The wind invariably blew from the north-west, and always strongly when setting the east quoin. After some loss of time waiting for the wind to moderate, 4 in. plastic pipes were used in varying lengths round the plumb wires with a gap at the location under test.

Mr J. K. Holt, Bertlin & Partners

The sector gates at Seaforth are rather unusual in that they do not have any bracing in the vertical plane, so that most of the weight of the gates is carried on the bogies. This is in contrast to most other sector gates throughout the world which are designed so that the hinges carry some or all of the weight. In view of the comments the Authors have made about the trouble experienced with the bogies, do they feel that there might have been some advantage in using bracing?

92. In the Paper it is stated that the sector gates at Seaforth are the second of the type to be built and installed in the UK. The first were installed at the entrance lock to Chichester Yacht Harbour in 1965, my firm being responsible for their design. The third sector gate installation in the UK is likely to be at the entrance lock at Brighton Marina, which we are also designing.

93. There are a number of different types of sector gate and I should like to illustrate this with Fig. 10, which is from a report[3] on a research project that my firm carried out for the National Ports Council (NPC).

94. Most sector gates have a face which follows a circular arc about the hinges. This arrangement ensures that all pressure forces pass through the pivots. The included angle of the sector in plan can be varied, but the minimum angle found in practice to give a satisfactory shape is about 60° and many existing gates have angles of 60–70°. Fig. 10(a) and (b) shows gates of this type. The first shows plain radial gates with seals on their faces so that movement of water past the gates occurs at the gap at the centre. The second shows an arrangement in which water flows not only through the centre gap but also through the recessed gate chambers at the sides, so increasing the rate of water movement past the gates.

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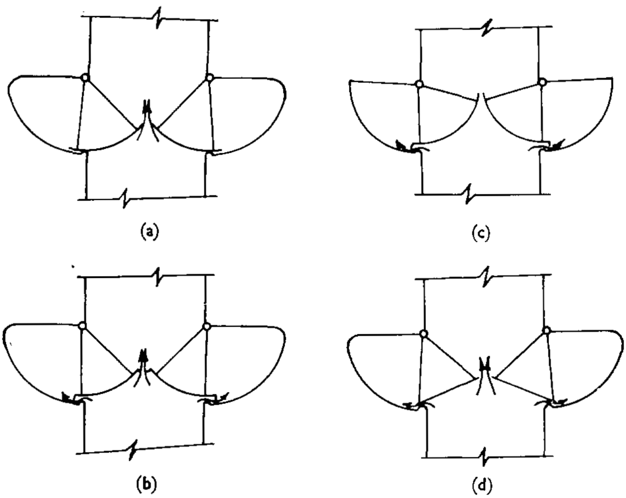

Fig. 10. Sector gate sluicing arrangements: (a) plain radial gates; centre sluicing (b) 60° radial gates with ears; side and centre sluicing (c) 90° radial gates with ears; side sluicing (d) delta gates; side and centre sluicing

95. Figure 10(c) shows gates with a sector angle of 90°. This arrangement enables water moving past the gates to pass only through the recessed gate chambers at the sides.

96. In our report[3] to the NPC we pointed out the advantages of the delta sector gate shown in Fig. 10(d). It is planned to use gates of this type at Brighton Marina. With the delta gate arrangement, increasing angular rotation of the gates during opening results in a progressive increase in the size of the gaps at the sides, enabling water to move past the gates more quickly. This can be a distinct advantage in some applications. In addition, construction is simplified by eliminating the curved skin of the more common circular arc gates and adopting a flat front face.

Mr R. E. West, A. G. Tate & Partners

I have always been an enthusiast for sector gates. They offer more potential for development than most other types of gate.

98. In the report[3] which Bertlin and Partners undertook for the NPC, with which I was connected at the time, the basic endeavour was to examine the reasons which had inhibited the use of sector gates in the UK and to produce a design as close to reality as possible. It seemed that while sector gates were of particular value as guard gates, they also offered considerable advantages if they were used in a lock, for not only would they be economic gates in their own right but it should also be possible to sluice through the gates and to eliminate any other sluicing system which might be necessary. Difficulties of turbulence etc. would arise if one were equalizing levels through very high heads, but it seemed that for low and medium heads which are generally required in the UK there was likely to be a good chance that this could be achieved.

99. One of the great advantages of the delta gate with the straight face along the front is that as the gate opens the gap between the gate and the fixed quoin widens progressively and there is a means of controlling the rate at which water passes from the high to the low side. This means that the gates can be opened a little way at the start and then, as the head gradually reduces, the gates can be opened progressively.

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Above all, they can be opened really wide towards the end and the period substantially reduced; this normally takes a very long time with orthodox sluicing systems.

100. One of the points which struck us at once was that with a straight faced gate the fundamental advantage of sector gates would be lost immediately with the resultant forces on the face of the gate theoretically passing through the hinge, and with no turning moment. When a gate is sluicing there is a difference in head across the face of the gate which is not necessarily balanced from one side to the other, so we were concerned that the type of forces there were liable to be with a straight faced gate could be handled. We therefore carried out some model tests. A pair of gates which was being designed for an opening of 100 ft width and 40 ft depth was modelled by the British Hydromechanics Research Association in timber, and tests were carried out to measure the forces, if any, required to hold the gates at a partially open position to allow water to pass through. The tests were done in a flume with the gates fixed at various angles of opening, in 50 increments. The water level on the rear side was progressively lowered to a fixed amount, the flow adjusted to maintain the levels, and the forces required to hold the gates in those positions were measured with a spring balance. This was done for various heads down to a maximum of a simulated full sized head of about 20 ft.

101. It was found that for gates of this size, at first they tended to close, which was good because it meant that if they were used in an emergency or as guard gates, if all else failed, all one had to do was to let them go and they would close. In addition, it was found that the maximum force, even at substantial head differences, was about 50 tons measured on the front face of the gates. It was thought that this was something which could be handled satisfactorily by the mechanism.

102. It seemed that, to be practical in a lock, it was essential for the gates to be buoyant. For certain applications, gates can be maintained in situ but for a lock it is necessary to be able to take them out for routine maintenance, or in case a ship hits them, so we attempted to design a buoyant gate which could be floated away. In practice it worked out quite well.

103. There was a double skin design with a straight face which would have reduced the fabricating costs substantially. It was braced horizontally and vertically with girders and taken back through the large box members directly to the hinges. The weight of the gate was supported on the top hinge, out of the water, so that it was easier to provide resistance to loading in two planes. The hinges were to be arranged so that they would lift free if the gate had to be under-set. There are very high forces through the hinges and if they are designed with a plane bearing material they can be fairly large, although this is practical. Therefore a roller bearing was devised which would be waterproofed by pressuring the inside with oil to a greater pressure than the water outside, and they could be kept in fairly reasonable proportions.

104. The bottom seal with a sector gate is a particular problem. It is even worse for the delta gate, for not only does it have to slide horizontally but the path followed by the bottom of the gate is not along the same track. Therefore after considering different types of seals it seemed that the best approach might be to have an inflatable seal, which had been used before. There are some at Dieppe. These lasted about ten years before acquiring holes and having to be patched and repaired. That is not too bad. The worst trouble has occurred about the tidal level on the side, where the sun has affected them. This type of seal would be used only across the bottom and consequently under water; it is possible to devise an inflatable seal which would be entirely retracted while the gates are operating. This should stand a fair chance of success.

Mr R. Daine, Ford and Daine

I was concerned with investigating the bearing failure that has occurred on the bogies of the centre gates. Out of this investigation have come two points to which I should like to refer.

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106. The first is that the side load that comes from misalignment of the rail has been re-estimated. There is no question of bad installation of the rail here. It is merely an engineering fact that one cannot get perfection of alignment to the degree where some small amount of sliding between the bogie wheel and the rail may occur. This can lead to quite high forces.

107. When the design of the bearing was received one of the possible faults investigated was the fatigue loading that can occur if the bearing material is rotating with the wheel round a fixed shaft. Therefore it was decided that in any re-design of the bearing a rotating live shaft and a fixed bearing material would be used. Essentially, this means that the bearing material has to be mounted in the bogie, and in making that mounting more room to fit in all the equipment was required. Also, it was necessary for assembly reasons to have a half shell coming round the bearings. We wanted to use the same bogie carriage and to investigate the effect of increasing the cut-out in the bogie, and the effect of increased side load. This cannot be done with a model of this type entirely, but what was used was a technique which was originally developed in the internal combustion engine field for having a quick look at stressed systems in redundant structures.

108. The technique consists of making a simple model using sheets of rubber. In only a few hours the model and the original bogie were constructed and various mechanisms were put in for loading it. These are bits of wood and wire. Loads can be applied in various directions, and one can see visually the sort of distortion which occurs when loads are applied in various directions. However, they are grossly magnified so that if there is any untoward distortion in any part it can be seen immediately.

109. The model was tested by looking for areas of particular distortion, then cutting out more rubber and sticking on another rib here or boxing in a section there, so that ultimately, with very little extra expenditure in metal, the extra metal was applied in the place where it was really needed and the structure was stiffened by a considerable amount.

110. Rendel, Palmer and Tritton then built a better model of the stressed area. This represents the final design which is to be used to carry the new bearings.

111. I would commend this technique as a powerful tool for looking at problems in stressing. It is not a substitute for doing the whole job on paper and in detail but it is a means of getting somewhere near the solution and focusing attention on the danger areas.

112. With regard to the choice of Railko bearing material for these bearings, it has been questioned whether buoyancy and a stiffer structure might have been a suitable approach to the design. It is possible to design a satisfactory bearing for the type of sector gate that Rendel, Palmer and Tritton have chosen, and in such a bearing one has to face the problems of dirt ingress and misalignment. In this respect I consider that Railko is an ideal material. First, it is relatively flexible, so that if distortion or misalignment occurs it is better equipped than, say, a bronze bearing material to make itself comfortable under these distortions. Second, it is tolerant to dirt. In one of the bearings that did not fail there had been ingress of stainless steel machine turnings which had come out of an oilway. These turnings were analysed at Imperial College. They occupied some 40–50% of the surface area available on the Railko material, yet that bearing had absorbed both them and the stainless steel shaft that they were running against, and was only lightly damaged and quite serviceable.

113. Silt ingress is likely and silt will similarly be absorbed in a Railko bearing material. This ingress of stainless steel, which has been perfectly absorbed by the material, is a strong indication of what an excellent material this is in its application. The fact that it has failed has been carefully investigated. A particular cause is this fatigue loading, but I do not think it is the only cause.

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Dr J. D. Hardwick, Civil Engineering Department, Imperial College of Science and Technology

An interesting example of flow-induced vibration occurred during the model studies of the Seaforth sector gates undertaken by the British Hydromechanics Research Association. One of the models differed from the prototype in two respects, each of which is often associated with flow-induced vibration. First, bogies and wheels were not fitted and each gate was therefore supported by its hinges alone, rather like a door. The model gates were thus very flexible and could oscillate in a vertical direction. Second, a horizontal, perforated plate in the shape of a sector of a circle was substituted for the radial arms. When there was flow from Seaforth Dock to Gladstone Dock through the gaps beneath the gates the perforated plate was often submerged in the turbulent flow of a hydraulic jump.

115. For certain gaps and differential heads each model gate vibrated with simple harmonic motion at its natural frequency, but only when the perforated plate was submerged. The reasons for this have not yet been fully resolved and a much smaller two-dimensional model constructed at Imperial College failed to reproduce the periodic excitation. Nevertheless, the evidence suggests that the vibration stems from an interaction between the movement of the gates and the fluctuating flow pattern in the vicinity of the perforated plate. It is not yet clear whether the interaction is caused by periodic instability of the hydraulic jump or a fluctuating condition of flow reattachment to the underside of the plate. Although this problem remains unresolved, it is not without relevance to future designs. The experience of the model studies underlines both the importance of designing stiff gate supports and the wisdom of withdrawing structural members from regions of highly turbulent, separated flow.

Mr J. W. Hunter, Coode & Partners

For years I worked with the Admiralty, which probably has more dock gates in the UK (and formerly overseas) than any other authority. The Admiralty turned against

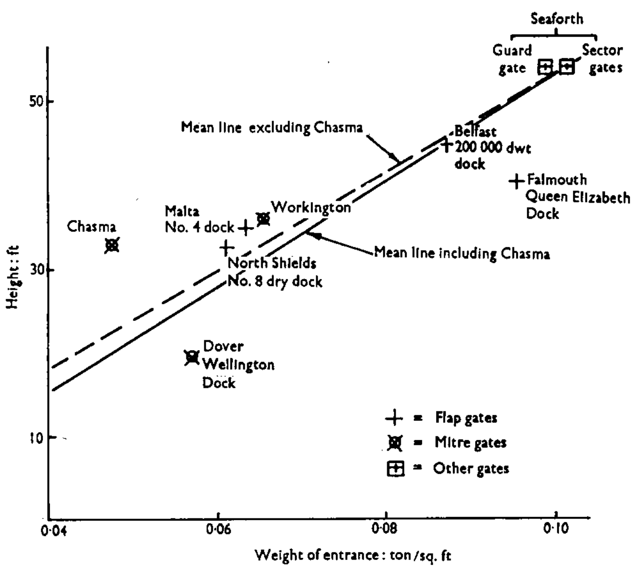

Fig. 11

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the use of any sort of rollers under caissons because it was found that rollers gave trouble, and this still seems to be borne out by recent dock gates that have rollers underneath them. I did not know until this discussion that the rollers of the Seaforth gates had given trouble, and this was one of the questions I was going to ask the Authors.

117. My firm used radial gates in a different set of circumstances from dock entrances, on the barrages of Indus Basin Scheme in Pakistan, where we installed over 250 radial gates, slightly smaller than those at Seaforth. They are 60 ft wide by a maximum of 32 ft deep. Trouble arose from vibration, which we found difficult to cure. I should like to know if the Authors have had any vibration troubles and if they have been able to cure them.

118. Fig. 11 shows, for various docks, the tonnage of steel in the gates per square foot of the entrances, plotted against the depth of the entrances. As the depths increase, naturally the tonnage per square foot increases. However, at Chasma the navigation lock had unusual proportions. The mitre gates there are 33 ft deep to close a 30 ft wide clear opening, so they have to be considered as a special case.

Mr J. E. D. Saner, Mersey Docks and Harbour Co.

I am responsible for the day-to-day maintenance of the sector gates. The bearing troubles with the gates have already been referred to, and as a result of those perhaps there has not been as long running with the gates as there might otherwise have been to discover all the troubles.

120. The only trouble so far of any significance has been a certain tendency for the hydraulic system to be subject to leakage, possibly due to the stepped opening causing repeated shock in the system. The key manual controls to the system have proved very useful on occasions, for if there is any fault in the automatic control system, with a tug Master insisting that his ship be passed through as quickly as possible, rather than hunting a fault in the control system, it is often simpler to switch to the manual controls to get the gate open and get rid of the shipping. This happens frequently at night. The guard gate has had, as a result, very much more use than normally expected. Generally, it has operated very well.

121. Troubles have been externally induced troubles of the control system. The lock and the latch have proved in their mountings to be highly vulnerable to shipping. This passage is exposed to the north-west wind and the windage of a large container ship going through the passage is such that she can berth very heavily on the sides. This has immobilized both the mechanical lock, which holds the gate in the closed position, and the latch which holds it in the open position. The sequence of opening is initiated by pressing one button on a control panel, so that there is an involved sequence in order to make all stages of opening occur in the right order and to prevent things going wrong. However, if there is a piece of the system missing it becomes quite a big operation to cut it out electrically and so allow the gate to work without it. I should therefore like to ask the Authors if they have considered operating first the latch which holds the gate in the open position separately, because it has been found in practice that even without it the gate does not drift out from the recess significantly when a ship passes.

122. I have fears that if the gate is not watched when locked in the closed position on the top of a rising tide, a negative head could result on it which would give trouble. In this connexion I should like to ask whether any consideration was given to holding the gate in a closed position with some sort of stall pump on the closing winch.

Mr W. J. Sivewright, Port of Bristol Authority

I have no connexion with the gates under discussion. However, the larger of the two gates described in the Bertlin and Partners report[3] to the NPC had its dimensions based on those which have been adopted for the new West Dock at Bristol.

124. With regard to the trouble with the bogies and the rollers, my first reaction to

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Fig. 4 was one of shock. I did not like the look of a canted axle carrying vertical load. Could it be that the troubles would have been diminished had the shaft been horizontal and the coning taken up by a cone wheel and a bevelled track?

125. From Paper 7600[4] it would appear that if and when the new lock is built at Seaforth the guard gate will then not be able to function if there is a disaster at the Seaforth gates. It seems that the guard gate can only accommodate a loss of water from Seaforth to Gladstone. Would it not have been better policy to design it to function in reverse at this stage, or is a second guard gate envisaged when the Seaforth lock is built?

Messrs Holloway, Feit and Wadsworth

Mr Wilson raised a number of points bearing on the actual behaviour of the sector gates in practice compared with the characteristics anticipated at the design stage. Some snatching was experienced with the operating ropes initially, particularly during the stepped opening procedure, and there was some danger of the ropes falling off the face of the gate, but this was overcome by operating at creep speed only during this part of the opening movement. No difficulties have been experienced with flow through the assymetric centre seal; in fact with a small gate opening and a large head differential the deflexion of the flow towards the side of the passage may be considered an advantage in that it tends to reduce the velocity into the adjacent dock. As far as we know the gates have not been opened under a large head since commissioning, but under a differential head of about 2 ft slow eddies into Gladstone Dock have been observed which have not apparently caused any trouble to shipping.

127. The only full-scale trial carried out in respect of flow conditions was the cracking open of the gates under a head of the order of 20 ft on the Gladstone side, during the flooding up operation for the Seaforth Dock. The discharge towards the side of the passage gave no cause for concern although some slight vibration was felt by those standing on the gates. Operating forces have not been measured directly, but oil pressures have indicated forces of the order of half the designed capacity.

128. In reply to **Mr Holt**, a gate braced in the vertical plane does obviate the need for bogies. However, it has the disadvantages of creating increased load and wear on the hinges, and a large gate such as that at Seaforth would be difficult to hold in vertical alignment at the skin because of the deflexion under varying loading conditions. Furthermore, the possibility of vibration in the vertical plane becomes very real, as **Dr Hardwick** has shown by his experiments. On balance it was felt that a gate supported on bogies was preferable. Mr Holt's proposals for improving the discharge through sector gates are interesting and most pertinent to the design of lock gates. They are not of great concern at Seaforth because the principal function of the sector gates there is to guard the Seaforth Dock and their use for levelling is occasional and incidental.

129. In connexion with delta gates, **Mr West** indicated that an operating force of 50 tons at the gate face would be anticipated. This is about five times that experienced on the sector gates at Seaforth, and would no doubt entail most massive and expensive machinery. With regard to oil-pressurized roller bearings, we would be apprehensive of the result of a breakdown in pressure permitting dirty water to enter the bearing. A material such as Railko would be expected to survive much longer under such conditions.

130. In reply to **Mr Hunter**, no troubles have been experienced with vibration of the sector gates, presumably because the skin of the gates was supported on bogies.

131. **Mr Saner** raised the question of the guard gate latch. During development the possibility was considered of the guard gate 'wandering' while in the open position in the recess as a result of the swell of passing shipping or the back swirl as the gate enters the recess. A latch was therefore provided, but in case its use was eventually found to be a disadvantage, it was agreed with the Harbour Company that a limiting bar would be placed across the housing of the latch, thereby preventing the latch bolt

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from falling across the gate path but allowing sufficient movement of the mechanism to operate the limit switches and sequence circuitry. This bar was necessary as the elimination of the latch circuitry from the main sequences of events would be a major task. Events have shown that the wash of passing ships is small but the back swirl can be considerable, and in our opinion the latch is of great help in keeping the gate in the recess without the necessity of keeping the back-tension on the opening rope.

132. Under the present system of locking ships through the Gladstone river entrance it is unlikely that a negative head will occur; nevertheless, the mechanical lock is capable of resisting a load of 200 tons (i.e. 100 ton impact load at any point on the waterline of the gate). The provision of a stall pump on the closing winch was never envisaged.

133. **Mr Sivewright** has suggested the alternative of a coned wheel on a horizontal axle for the sector gate bogies, running on a bevelled track. Although this might make construction of the bogie simpler it is thought that it would result in slightly increased moments on the bearings, and it would not therefore have helped the present difficulties.

134. It has always been understood that if Seaforth Dock were to be provided with its own river entrance the guard gate would become inoperable as differential heads from Gladstone to Seaforth could become normal, but of course its secondary function of being used at a caisson check in six other positions in the Liverpool dock system still applies.

135. Referring to **Mr Dain**'s remarks on the possible causes of failure of the wheel bearings, consideration of all the evidence now available has led to the final assessment that failure was due to the variable high tracking forces at the bushes, which would explain why five bearings failed and three did not, together with the effects of heavy cyclic loading, and was probably initiated by observed local pitting in the bearing material similar to that occurring in metal bearings as metal fatigue.

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