Main drainage at Weston-super-Mare

by

G. Hedley, A.M.I.C.E.

Mr W. B. Harris (Partner, C. H. Dobbie & Partners) congratulated the Author on his detailed account of the major improvement scheme at Weston, which had been carried out in very difficult ground circumstances, and also congratulated him and his former chief on having been bold enough to modify the design to take advantage of a tenderer's method of execution. A debt of gratitude was due to the Author for his description of the difficulties encountered and also for providing the details of unit costs.

104. On the question of discharge into the sea, in view of the increasing public interest in the matter of the discharge of crude sewage into the sea it was appropriate to make some reference to this aspect of the matter as it affected Weston-super-Mare. In 1955 Mr Harris's firm had been engaged to carry out a hydrographic survey of the bay at Weston, with particular reference to the proposed new sewer outfall at Black Rock. As would be seen from Fig. 1 of the Paper, the bay was an open-sided rectangle with the town and pleasure beaches on the longer side facing west; Birnbeck Island was to the north and Breandown to the south. The rise and fall of the mean spring tides was 37 ft, exposing a foreshore over one mile in width. A strip of sand 200 yd wide fronting the town was covered by spring tides only; the neap tides hardly left the mud. The sewer outfall was in the south-east corner of the bay.

105. With the assistance of a specialized firm they had carried out a series of observations during the spring, intermediate, and neap tides and the results obtained had been checked by current meter readings at three selected points: the point of discharge, the mouth of the River Axe at M.L.W.S., and an intermediate point. They found that Breandown, protruding at right-angles to the main axis of flow in the Bristol Channel, caused a clockwise current to be set up in the bay as soon as two hours after low water, and this outward flow caught up any solids deposited on the mud at low level and carried them out to sea long before the level of the tide reached the sand. Sewage discharged later on the flood tide was carried up into the River Axe, which seemed to act as a flushing reservoir, because Mr Harris had seen very little fouling of the banks even at spring tides which covered the saltings. The degree of dilution in the river alone was 1 in 250 for spring tides and 1 in 100 for neap tides. On ebb tides it was carried straight to sea. Crude sewage could be discharged safely throughout the whole tidal cycle with all tides, a very unusual and fortunate circumstance.

106. The Clean Rivers Act, 1960 (which he did not think applied to Weston) recognized that River Boards should have special regard to extra dilution and dispersion afforded by discharge into tidal waters, and in trying to balance amenity and economics before schemes of treatment or even partial treatment were undertaken, a thorough investigation of tidal currents and the stability of the sea-bed was justified.

107. He noted that at Weston comminutors had been installed. While these would make the solids less obvious, had the Author any evidence of their effect on the rate of oxidation of the sewage?

* *Proc. Instn civ. Engrs*, vol. 26, September 1963, pp. 31–50.

108. Finally, he had one or two questions bearing more directly on the Paper. In § 58, what was the significance of the settlement of the cofferdam at the rate of $\frac{1}{2}$ in. per week? The pumping station was founded on hard material 50 ft below ground level and the piles were 75 ft in length. He wondered whether the piles or the entire surroundings were settling.

109. From § 61 it seemed that most of the piles in the cofferdam had been lost. In any further construction, would the Author recommend their integration into the design of the permanent structure? With the advent of materials having thixotropic properties, would it not be possible to construct a circular wall of concrete which could form part of the wall of the station itself?

110. In § 90 reference was made to the choice of the pipes for the outfall part of the scheme. What were the factors which determined the selection of steel pipes, which needed fairly elaborate protection? A short length of extra-strength concrete pipe would probably not have been heavier to handle and might have been cheaper.

Mr S. J. A. Asher (Chief Engineer, Sewers and Rivers Dept, Birmingham Corporation) added his congratulations to the Author for producing a Paper which was of interest not only to those engineers who devoted their lives to the subject of main drainage, but also to any engineer who had to deal with bad ground, which meant to all civil engineers at some time or other.

112. So far as Mr Asher could see from the data given in the Paper, the general gradient of the main sewer appeared to be about 1 in 600. That was quite steep for a sewer of the size in question. No doubt in order to produce the result described in the Paper there had been a great deal of balancing and juggling with sewer sizes, depths, pumping station heads and so on and the relative economics of these various factors. Perhaps the Author would enlarge on that.

113. Mr Asher had visited Weston when the work described had been in progress and had found it very interesting. It was not often that drainage engineers could produce anything so spectacular as a vertical-sided hole 100 ft in diameter and 50 ft deep. It had been very well worth seeing. In that respect he would, like the previous speaker, congratulate the Author and his then authority on their courage in scrapping an entire design because of an idea put forward by a contractor. This underlined the fact that for any job that was even slightly out of the ordinary, co-operation at an early stage between the man who built it and the man who designed it was of the utmost value.

114. Mr Asher and the Author had worked together for some years, and at that time the Author had had a reputation for ingenuity. More than one 'Hedleyism' had appeared on the drawing board. A number of features of the design of the main drainage scheme at Weston showed that he had not lost his touch. In particular, the junction manholes were very ingenious and it would be interesting to know how they worked in practice. Had they worked as well as the Author hoped? In particular, could that be said of the counter-weighted ladder? Mr Asher was dubious about things that moved up and down in sewers, because one never knew how long Fred would continue to grease them. The Author could probably say that they had indeed been successful.

Mr H. W. Dupree (Partner, Sir Owen Williams & Partners) said that he knew Weston-super-Mare as a pleasant seaside town and found it extremely interesting to learn something of the inside story of the drainage arrangements there.

116. On the question of the possibility of pollution off the beaches up and down the estuary, he had intended to ask what preliminary investigations had been carried out. He wondered whether there was now any evidence of pollution either on the Weston beaches or on other beaches in the estuary.

117. He had been impressed, as other speakers had been, by the flexible approach adopted to the design of the scheme, and notably by the design of the pumping station

being changed as the result of a contractor's tender design. The revised plan for a circular structure seemed very satisfactory. Had it resulted in an increase or a decrease in the overall cost of the pumping station?

118. The economics of any scheme were always of interest, and he was interested in the comparative economics of the deep sewer, with the resultant difficulties encountered in the tunnel. Mr Asher had referred to the same point. The Author had done nothing to minimize those difficulties, and had not made the job sound easy. It would be interesting to know the comparative economics of the scheme adopted as compared with the alternative of shallower sewers and additional pumping stations.

119. Again on the subject of costs, could the Author give some details of the supervisory staff employed on the scheme and the cost of supervision? There was reference to various difficulties and even to mistakes in the tunnel contract. The Author referred in § 83 to 'excessive supervision' and in § 89 recommended that 'each face should be visited at least once during the shift by supervisory staff from both sides'. That seemed far from excessive and, Mr Dupree suggested, sounded a little inadequate for works of the type in question. He wondered whether if a sufficient number of competent inspectors had been employed at the faces, some of the difficulties and mistakes (if they were mistakes) would have been avoided.

120. It had been very satisfactory to have such a clear description of the work and one could wish that many larger jobs were as well reported and documented. With the movement of staff from one office to another—the Author himself had moved—such a permanent record must be of the greatest value.

Mr T. Hedley (Senior Engineer, Messrs J. D. & D. M. Watson) began by stating that he had a vested interest in the subject, as the Author was his brother. That did not mean, he added, that he had had anything at all to do with the scheme, nor had he discussed it with the Author or anyone else, so that he welcomed the opportunity to take part in the discussion, although some of his points had been anticipated.

122. He proposed to divide his questions and comments into two parts; first, what might loosely be described as design, and secondly, construction.

123. With regard to the design hydraulics of the system, in § 20 it was stated quite categorically that gravity discharge was not possible. If the figures in § 63 were examined, assuming that one of the dry-weather-flow pumps was a standby, a dry-weather flow of about 2500 gal/min could be deduced. This gave a ratio of storm-water to dry-weather flow of about 40:1. In the speaker's experience this would seem to indicate that the system had been designed on the basis of a one-year storm. For such a deep pumping station he wondered whether this was enough. His experience would lead him to say that it was not, but he would not be so foolish as to state in the discussion what he thought that it should be. He would like to know what rainfall criteria the Author had used in this design.

124. His next point also concerned flow. From the figures given it seemed that the sump capacity was about 50 000 gal, or approximately 1 to 2 min pumping rate of one of the storm-water pumps. That was a very small capacity. He had had experience some five years ago of trying to relate variable-speed pumps with low-capacity sumps. That experience had not been with quite the type of pump used at Weston, but with a variable-pitch axial-flow pump. To avoid hunting it had been found necessary to get the full change in pitch impeller in 20 sec. Perhaps the Author would enlarge on his method of control and, if the figures were available, say how long it took one of his pumps to change from minimum to maximum pumping rate.

125. The storm-water screen gave rise to some misgivings. In the speaker's experience a screen of this sort did not clear itself. He had known screens of this type to be put in horizontally and they also had not been successful. Had the screen used at Weston proved an exception to the rule?

126. Passing to matters of construction, he would like the Author to enlarge on the pipe-bedding techniques and to say whether the silt-sand base stood up to the

normal constructional traffic during the laying processes and also whether any subsequent check had been made to ascertain whether differential settlement had taken place.

127. The Author had already referred to the question of air losses. The speaker too regarded the loss as rather high. When his firm were involved in the construction of a tunnel in chalk about two years ago, fissures of up to $\frac{1}{2}$ in. were experienced, and losses of this order had been sustained. The tunnel was smaller, but it was found that by using polythene on the face and on places which had not been grouted air losses could be reduced by 25%, and in these conditions this 25% had effected a saving of the order of £20 a day in the provision of air. Had the Author used any methods of that sort to reduce air losses?

128. Had the grouting in air been carried out by the traditional methods? On the job to which the speaker had just referred, due to the smallness of the section of the tunnel which was being driven, either the tunnel had to be enlarged so as to provide passing bays for mixing grout, storing cement and so on, or a method devised for mixing on the surface. The latter course was adopted and the contractor had devised an ingenious system which consisted of a counterflow mixer on the surface at the head of the shaft, the slurry being pumped straight down to the face with mono-pumps. A pressure of about 80 lb/sq. in. had been used to place the grout. They tightened up at about 100 lb/sq. in. and the maximum pressure experienced at the mono-pump had been 200 lb/sq. in. Some time was spent on working out the design, and most of the engineers, himself included, had been trying to work out a ring-main system to keep the grout circulating and avoid a long dead leg. The length of drive had been about 500 ft. The answer had been provided quite simply by the tunnelling foreman, who said 'You send the grout down to me and I will send it back to you when I have finished with it.' That had been what happened; when he had finished grouting he connected up the high-pressure air and sent it back.

129. In conclusion, were the costs given in the Paper based on the tender figures or did they include the final costs of the job, including claims, extras, etc.?

Mr J. Miller (Chairman, C. V. Buchan & Co. Ltd), whose company had been responsible for the construction of various sections of the Weston main drainage scheme, said that without doubt, from an engineering point of view, the pumping station had been the most interesting of the various sections with which they had been concerned. As contractors they were, of course, primarily interested in whether they were going to make a profit, but in this instance, as engineers, they had been very interested in the design of the pumping station, particularly when it was changed over from a rectangular to a circular plan.

131. It had surprised him that all the previous speakers had commented on the fact that the contractor had been able to contribute something to the design of the pumping station, with a slight raising of the eyebrows. Contractors could always contribute something towards design, and, in this case, he liked to feel that as a result of the numerous discussions with the Author on this subject, they had been able, even as contractors, to contribute to the design and construction of what, in his opinion, was a unique pumping station.

132. He had two questions to put to the Author, one of which had already been mentioned by Mr Harris but from a slightly different point of view. It concerned the design of the cofferdam. Under the contract Mr Miller's company as contractors had been responsible for the design of the cofferdam, subject to the approval of the engineer. It had been designed by his company using ring beams for the internal support, a system which had been extremely successful from the point of view of construction, in that it gave them a completely clear working space in the middle of the cofferdam. The point he wished to emphasize was that it had been designed completely independently of the pumping station itself.

133. That brought him to the question which Mr Harris had already asked,

namely, whether the Author, if designing a similar scheme in the future, would not consider it desirable to incorporate the design on the cofferdam in the design of the pumping station. Mr Miller would have thought it much more economical to do so and he would be interested to hear what difficulties the Author would envisage in incorporating the two designs.

134. That led to his second question, which related to the method of billing the cofferdam. It had been billed as a lump sum item including provision, driving, and withdrawal of the piling—and he emphasized withdrawal—together with the provision of the internal support. When the time came to extract the piles a stage was reached when the actual effect of the extractor was increased beyond the tensile strength of the piles, resulting in the removal of the tops of the piles in the jaws of the extractor. It had been obvious, therefore, that they could not get the piles out of the ground, and this had led to some discussion between the Author and Mr Miller's company on who was going to pay. That question had been settled, but it gave rise to a good deal of discussion, and therefore Mr Miller asked his second question: did the Author agree that if the design of the cofferdam had been incorporated in the design of the pumping station and it had been billed as permanent work this would have been much fairer to the contractor and would have avoided the lengthy discussion which had taken place on the question of payment, which engineers must find embarrassing. Finally, did the Author consider that the steel sheet piling could be advantageously used as a permanent feature of the design of such a pumping station?

Mr P. F. Morgan (Allen Gwynnes Pumps, Ltd) referred to the Author's remark that on re-reading the Paper, he felt that he had made the work seem rather too simple. Mr Morgan thought that the Paper seemed simple because the clear way in which the Author had set it out enabled it to be easily understood; he also believed that the best engineering solutions were always the simple ones. He joined with other speakers in congratulating the Author both on the Paper and on the scheme which it described.

136. The choice of diesel-electric drive confirmed a curve shown in the symposium on mechanical equipment for sewage purification works held in 1962 at the Institution of Mechanical Engineers;¹ but that curve had been based on the assumption of no parallel running with the public supply. It showed that for flows of 90 cusecs or more the introduction of diesel-electric drive was justified. It would be of interest if the Author would give some further information about the choice of prime mover.

137. The maximum tide variation of 45 ft, together with the wide variation in flow which must be expected in storm conditions, involved the pumping plant in a very wide range of duties, and it would be of interest if the Author could give further information on the matching of the pump characteristics to the duties.

138. Fig. 9 would perhaps answer the question put by Mr T. Hedley. It was not a 'fullway' pump; these were mixed-flow pumps. Mr T. Hedley probably liked shrouded impellers, and shrouded impellers could also be fitted to that design.

139. The Author had not gone back to the beginning in dealing with the model tests. These had gone on for many weeks. The model had been constructed to a scale for the storm sump of 1:18 and Perspex pipes had been used to ensure that no air-entrainment was taking place, because they enabled air to be seen passing up the pipes. Fig. 10 showed the original proposition, with the dry-weather-flow sump and a weir coming over into the storm sump. Fig. 11 showed the sump in operation, running at the correct Froude number, with a level in the storm sump of 84.00 (referred to arbitrary datum 100.00 ft below O.D.). Clearly those sumps were unacceptable as they stood.

140. A completely new approach had then been tried, which had been combined with the change in shape of the station. Fig. 12 showed the sump operating with 240 cusecs (which was also the flow in the former case) and a level of 84.00. It would

FIG. 9: CROSS-SECTION OF PUMP AT WESTON-SUPER-MARE BLACK ROCK

FIG. 10: ORIGINAL PROPOSITION

FIG. 11: SUMP IN OPERATION

FIG. 12: SUMP OPERATING WITH 240 CUSECS AND LEVEL 84.00

be seen that the flow conditions were quite acceptable and no air was being drawn into the pipes.

141. The final arrangement (Fig. 3) involved altering the pumping station, and so the sump as finally arranged had been somewhat different, but there was a very large storage capacity, which had produced reasonable flow conditions.

142. He wished to emphasize that model sump tests were always worth while, and were particularly so in a wet sump arrangement; but, as this series of tests showed, they could also be of great value in a dry sump arrangement. There were research associations, pump manufacturers and some of the larger civil engineering contractors who could undertake these model tests, and the money spent on them was always more than recouped—he would say at least five times over—in the full-scale works.

Mr K. Schwarz (Laurence, Scott & Electromotors Ltd) stated that one of the most striking points brought out in the Paper was that the whole concept had been carried out with complete co-ordination and co-operation of all the different interests, which he believed had contributed largely to the success. Such co-operation did not always happen, but it made the greatest contribution to the overall economics of any scheme, main drainage being no exception. Some of the points raised in the Paper and discussion required to be amplified, particularly from the electrical design point of view, in order to clarify various matters.

144. The dry-weather-flow conditions were dealt with by fixed-speed motors, a conventional method not needing further explanation. The storm-water pumps, however, dealt with a wide range of flows, 22–130 million gal/day associated with a wide range of head, 25–36 ft minimum to 36–54 ft maximum. Complementary to the pump design description by Mr Morgan, Mr Schwarz was interested in describing the variable-speed A.C. commutator motor performance and particularly the design co-ordination between the motor and pump for the hydraulic conditions. It was not always realized, though the Author had stated it forcibly, how the use of variable-speed pump drives resulted in economies in initial capital cost, and in increased operational efficiency. The former resulted from the reduction in the number of pumps, smaller sump capacities, reduction of pipework, etc. possible at the design stage. The latter was achieved by designing the automatic operation of the pump sets to take due regard of the combined pump and motor efficiency under all hydraulic conditions.

145. Careful study was made of the three major parameters determining the operating conditions: the sump level, the flow, and the tide level. The main automatic control parameter chosen was the sump level, while the number of pumps was selected by the flow, and the tide level was used to adjust the minimum speed of the sets to such a value to ensure efficient pumping under all conditions.² By determining the changeover points correctly, a high overall efficiency of the pump sets was achieved throughout, together with complete control over the flow at all times, utilizing simple electro-mechanical automatic control equipment. Moreover, the rate of response of the pump sets was so designed that the sump capacity was sufficient for all expected rates of change of the inflow, taking into account further the large capacity of the sewer itself. Consequently, the economies mentioned above were achieved.

146. Moreover, the relatively low starting current of the large storm-water-flow pump A.C. variable-speed driving motors allowed each diesel-alternator to be sized to cover the demand of one motor only, i.e. avoiding any necessity for over-sized diesel sets, the alternators being designed for high switching capacity to ensure a stable supply voltage.

147. In conclusion, the Author and his colleagues were to be congratulated on the co-ordination they achieved between the civil, hydraulic, and electrical engineering aspects.

Mr D. H. Hughes (Messrs J. D. & D. M. Watson), returning to the subject of the pumping station, said that the change from the rectangular to the circular design had presumably been made because the circular structure would be cheaper. He found it difficult to believe this, and, as he had been associated over the past few years with the design of a rectangular station for the East Middlesex main drainage scheme, he wished to quote comparative figures which might be of interest.

149. The Middlesex station was 64 ft deep and it incorporated six electrically-driven pumps of 330 h.p. each for dry-weather flow and four storm-water pumps driven by dual-fuel engines of 650 h.p. The total pumping capacity was about 200 000 gal/min, which was about twice the capacity of the Weston station. Internally the station, including the wet well, was 100 ft long and 30 ft wide. This was only 60% of the internal area of the Weston station, which was 82 ft in internal diameter.

150. The Middlesex station had been constructed in a piled cofferdam, using the same piling as at Weston but designed for the piles to be left in. As a result the overall area of the excavation was only 50% of that for the 100-ft-dia. circular cofferdam at Weston. This, of course, would bring about reduced excavation costs. By taking advantage of over-site excavation the piles were 58 ft in length, as compared with 75 ft at Weston. The cost of the cofferdam (including that of the piling left in) was £35 000, which compared with the figure of £63 000 given in the Paper.

151. In his submission these figures indicated that a rectangular pumping station could be an economic design and he would have thought, more economic than a circular one. The figures also made the point that it paid to design for piling to be left in. In reply to Mr Miller's question, Mr Hughes did not think that any engineer would have the courage to incorporate these piles in the design of the final structure. That might seem foolish, but it was a fact. It was still cheaper to leave them in.

Mr H. R. Oakley (Messrs J. D. & D. M. Watson) said that he found much of merit in this scheme, and the Paper bristled with interesting points.

153. He would first ask the Author in his reply to enlarge on the question of the structural design of the sewers, which was a subject of current interest. There were intriguing references in the Paper to special reinforced-concrete sewer pipes and to vibrated beds, granular fills, and difficulties in construction. It would be interesting to know how the structural design had been approached, and what difficulties had been encountered with the granular fill, which was often happier on paper than in practice.

154. His second point concerned the design of the manholes, which were illustrated in Fig. 5, from the point of view of the safety of workmen who required to enter the sewers. Members of the Safety in Sewers Committee would speak with more authority, but he deprecated introducing workmen through the top of the sewer by a counter-weighted ladder, and the absence of benching, handholds, and safety chains. He thought that economy had been achieved at the expense of safety and convenience.

155. His third point concerned the circular pumping station. He was less enthusiastic than some previous speakers about this form of construction. This form was not unique, but it was uncommon because it did not often prove economic or convenient. The structural design was obviously attractive, but circular houses were not very nice to live in, and to fit machinery and other facilities into a circular structure gave rise to various difficulties, some of which had been mentioned in the Paper. The economics too seemed doubtful, as he understood that the lowest of the original tenders had in fact been based on the original design of a rectangular station.

156. He endorsed the desirability of model tests in sump design, but found it surprising that this should be regarded as the responsibility of the pump manufacturer; in his view the design engineer was responsible.

Mr G. T. J. Fox (Imperial College) observed that on looking at the station one wondered why the idea of axial-flow pumps had not been pursued a little further, because it was fairly obvious that it would be economic, having regard to the size of the very large well. The usual criticism of the use of axial-flow pumps for sewage was the tendency to collect solids on the fixed blades, but the station at Weston had fairly large pumps, and he wondered whether axial-flow pumps would not have been a better alternative. It would have cut the cost of the civil engineering works and might have warranted the idea of the moving or variable pitch blade.

158. The dry-weather-flow pumps had comminutors and there should be very little trouble about solids getting on their blades, but perhaps there was a slight danger with the surface pumps. Would the Author enlarge a little on the choice of pumps and say what had made him choose the mixed flow?

Mr W. A. Feather (Partner, Messrs Lemon & Blizard) expressed interest in the Author's comment in § 100 that 'Where a heave occurs in a trench bottom before the site concrete is placed, this is not accompanied by obvious or visible evidence until after the pipe is laid and settlement occurs.' That sounded as though it was a general observation; perhaps the Author would say whether it was an observation made in the light of experience which he had gained in the laying of these sewers in Weston, and perhaps he would explain how, if a trench bottom heaved, a pipe would settle afterwards.

160. A heave might be looked on as being the effect of unbalanced forces, the external pressure of the natural ground head causing displacement, so that when the pipe was laid and the trench refilled it would seem that the forces were equated and that there would be no residual force available to cause settlement. Did the Author feel that what he referred to as 'heave' might be due to some expansion of the ground when the overburden was excavated in the digging of the trench, and when the pipe was laid and the trench filled there was recompression of the formation on which the pipe had been laid? If the Author would give his views on this, founded on his experience at Weston, Mr Feather would find it very helpful.

The Chairman, Sir George McNaughton, said that the Paper described interesting engineering work. Very seldom in municipal drainage works were there major engineering works such as had been described. The works had been designed by the local authority engineers and the Author had played a very prominent part in the design.

162. He found it difficult to raise any points, because the discussion had disclosed a large measure of agreement. The only real argument was whether a rectangular or a round cofferdam was the more economic. He had tried to do some calculations, which showed that with a round cofferdam a little piling was saved, but whether or not it was suitable must depend on the layout inside it. The overriding consideration was that the real economy would depend on the skill with which the internal strutting was designed to give the best working conditions inside. It was not simply a question of the cost of the cofferdam but of having freedom of operation to do the rest of the job.

The following contributions were received in writing:

Mr H. H. Hunt (Director, Norwest Construction Co. Ltd) and **Mr J. G. Davis** (Chief Engineer, Norwest Construction Co. Ltd) wrote that in § 52, with reference to the difficulty in maintaining verticality of the piles, it was stated that 'the problem was finally solved by forming a metal cross-halving which, whilst permitting an ordered single withdrawal, allowed alteration to be made in pile width to regain verticality'. Would the Author please give a little more detail of the method used?

164. It would be of interest to know why a dragline was used only for the first 8 ft, since one would normally expect a dragline to be quicker than a grab, and it would seem that there was plenty of scope for the dragline to go well below 8 ft.

165. In §§ 51 and 61, reference was made to the piles being supported by five reinforced-concrete ring beams and to the difficulty in extracting the piles. This led them to ask the following questions:

- (1) Were the ring beams cast hard up against the steel piles and into the pans, or was some membrane incorporated to prevent adhesion between the piles and the concrete?
- (2) Were any hooks or brackets incorporated to fasten the rings to the piles, or did they depend on adhesion to prevent the rings sliding down?

166. If in fact all the beams were cast hard up to the piles, it would seem almost impossible to withdraw the piles, unless the beams were demolished as backfilling proceeded.

167. When the cofferdam was observed to be sinking (§ 58), presumably there would be a drawdown of the surrounding ground. If this drawdown did in fact occur, how far beyond the cofferdam were its effects observed?

168. With regard to the manhole design (§§ 44-48), it was gratifying to note the engineer's appreciation of the practical and economic aspects of the problem and the resulting economy. If this type of manhole proved as satisfactory in practice as it would appear on the drawings, there would seem to be considerable scope for its incorporation in many similar contracts.

169. Referring to § 83, the difficulty of obtaining good quality construction of the tunnel rings was appreciated, particularly nowadays when good tunnel miners were not easy to come by and could obtain high wages anywhere.

170. In the past they had successfully tried dividing the bonus payments into 'progress' and 'quality' payments, the 'quality' bonus only being paid on the erected rings being passed as satisfactory by the inspector and the agent or his representative. That inspection had of course to follow closely on the work so that the men were not kept waiting for the bonus, but any legitimate cause of complaint by the inspector had to be put right by the gang before payment was made. One of course got the usual excuse: 'That was the other shift', and difficulties arose if at change of shift a ring was only partly completed. However, on the whole it worked. Whether it would work nowadays was doubtful!

Mr E. A. Dyer (Messrs J. D. & D. M. Watson) wrote that although the trench manhole shown in Fig. 5 was novel and ingenious, he considered that safety had been sacrificed for expediency. When the invert of the junction pipe was less than about 8 ft above lower platform level, the area of fixed platform available for standing, or the storage of tools and materials was totally inadequate. Of even greater importance, this lack of space on the platform could seriously hamper the removal of an unconscious or injured man. The clear manhole opening at the top of the fixed ladder appeared to be insufficient to allow ingress or egress by a man wearing breathing apparatus, or the removal of a casualty. In both Figs 4 and 5 a noteworthy omission was the absence of safety chains across the sewer on the downstream side of the manhole.

172. As the Report on Safety in Sewers and at Sewage Works (published by the Institution in collaboration with the Ministry of Housing and Local Government) was now available, it was essential that designers should make every effort to ensure the safety of persons engaged on the maintenance of their works by implementing its recommendations.

Mr J. L. Arnold (Principal Assistant Engineer, Sewerage and Special Works Section, City Engineer's Dept, Liverpool) and Mr A. R. Goode (Chief Assistant Civil Engineer, City Engineer's Dept, Bradford) wrote that they were both engaged in the preparation of the scheme as originally presented to the Borough Council and the Ministry. They congratulated the Author on a very interesting paper.

174. It was gratifying to note that there was only one major change as a result of further consideration during the preparation of the contracts. This change was in fact from the original proposal for a reinforced-concrete box culvert in open cut to a circular tunnelled section at greater depth. They asked whether this change was the result of economic considerations, bearing in mind the increased cost of pumping against a head some 25% greater for the life of the scheme, say 100 years. Was tunnelling the more attractive from the point of view of disturbance, etc.? The Author had made a point of some of the difficulties in controlling the tunnelling shields in the soft ground encountered. To what extent were these difficulties reflected in the line and level of the finished rings and sewer? If the Author had to repeat the work at Weston would he still choose tunnelled construction?

175. The construction of the deep sewers in special reinforced-concrete pipes was

interesting, especially the method of maintaining the flexibility of the Cornelius joints with additional rubber rings. Steel pipes were used for the outfall, and early design had shown that steel pipes would be economically feasible for the sewers across the 'plain'. In addition it was expected that the relatively flexible steel pipeline with, nevertheless, rigid joints, would maintain a truer invert level than the short length, flexibly-jointed concrete pipes. What were the factors which determined the choice of the concrete pipes? Did the experience obtained in laying the large (and long) outfall pipes influence the decision at all? Had any checks been carried out on the concrete pipes since they had been in use to determine whether any movement had taken place?

176. Could the Author throw some light on the decision to connect the main sewers in the town centre to the main trunk sewer at the back of the town by way of Locking Road and what they believed to be still the Corporation's salvage-tip, instead of from the Station along Old Junction Road?

177. With regard to the pumping station it was interesting to see how a rectangular superstructure below ground level had been incorporated into a circular retaining wall providing light wells. Had any special treatment been given to the concrete facing of these walls to ensure a continuing high reflectivity? It would be interesting to know whether the possibility of using the cofferdam as the external shuttering was considered prior to the difficulty in extracting the sheet piling. The presence of a firm bed of hard silty sand to support the pumping station without piling seemed extraordinarily happy, since a preliminary borehole in the vicinity had shown nothing better than peat, clay, and soft sand with shell-beds.

178. The manhole design for the deep sewers was most commendable and presented a very ingenious method of containing the whole work within the trench limits. From a hydraulic point of view the side entry with an almost completely eliminated forward velocity had much to commend it, but from a practical point of view the use of such devices as a counter-balanced ladder gave them some doubts. Excellent when new and carefully maintained, such devices had a tendency to be forgotten as they grew older. Had the possibility of premature corrosion in the manhole atmosphere been considered, and what steps had been taken to counter this? Had any special steps been taken in proofing the hinged platform against corrosion? The safety of the operator descending the manhole must depend on this, and from the diagrams, they appeared to be of a fairly light construction.

179. In addition, they felt that some brief notes on the basis of the original design would be of interest. They would be interested to know of any points which the Author found desirable to modify in the course of his work at Weston.

180. The foul flow was calculated on a water consumption of 35 gal per head per day, and an infiltration into the old sewers of 50% of the dry-weather flow was allowed for. Future light industry of the type likely to be established in Weston was estimated to provide a foul flow of 1 cumin/gross acre.

181. The storm flow was investigated carefully since all the storm water from the combined-sewerage areas would have to be pumped. Fifteen years of storms were analysed to produce a storm intensity curve which followed the 'Ministry' curve up to 40 min, and thence to 3 hours, represented by the formula: $R = 60/(T + 50)$.

182. A very careful assessment of the impermeability factors was also necessary, and this was based on the detailed investigation of 25 representative areas. It was found that two curves based on the number of houses per acre were necessary, the one applying to older development, and the other to the newer. The dividing line was around the year 1930. Comparative values were as follows, the figures in parentheses being an assumption of all roads, roofs, etc. being fully impermeable and the remainder fully permeable.³

Houses/acre	8	12	16
Impermeability factor, pre-1930, % . .	40(41)	50(45)	58(66)
Impermeability factor, post-1930, % . .	25(22)	30(26)	38(35)

The post-1930 figures for 16 houses/acre were extrapolated. Time of entry was estimated to be between 1 and 8 min, but averaged 4 min, and run-off was calculated by the usual Lloyd-Davies method.

183. A hydrographic survey showed that there was a clockwise current in the Weston Bay which maintained the outflow of the River Axe at all times except the peak of the incoming tide. The design height of the tides was taken as being the predicted high water above which only 30% of the tides were higher.

184. Allowance for storage in the main sewer above the pumping station (the then square-section culvert) showed that the maximum pumping rate required could be some 20% less than the maximum rate of flow into the sewer.

Mr A. W. Shilston wrote that it would be a great loss to the literature if such qualitative data that might exist on sub-soil characteristics at the various locations referred to in the Paper, measured in soil mechanics terminology, could not be reproduced in the discussion. That would enable a more succinct appreciation to be made of the behaviour of the soft silty clay during the caisson sinking, tunnel driving, and heaving in the pipeline trench bottoms.

186. With further reference to fundamental data, did examination of the existing sewers reveal any matters worthy of comment? For example, did the invert of the 48-in.-dia. brick sewer, to which reference was made in § 5, appear to have been laid successfully to a uniform grade in what were presumably sub-soil conditions similar to those experienced nearly 100 years later? What was the condition of the brick-work?

187. With regard to the tunnel driving, one felt on reading the Paper that the scale of the problems met at Weston was so unusual that the temptation to ask for more information was irresistible! Would it be possible to include in the discussion a sketch of the shield showing the features to which reference was made in § 82?

188. The implications of using a shield in a conventional reinforced-concrete segmental tunnel was a subject which Mr Shilston wished to raise. He would imagine that in the soft silty clay, provided that settlement of the shield did not occur, undue pressures would not be set up as the shield moved forward. But in fact at Weston the shield did not behave in that manner, and he would like to ask the Author whether local crushing of the segment flanges was ever experienced in practice.

189. The usual need to follow close behind the face workers with the caulking in a compressed-air tunnel, to mitigate air loss, was referred to in § 87, but one was left to speculate on what happened if pointing of the joints followed too closely behind the face and within the influence of the shield rams. Would perhaps the best procedure in similar conditions be to carry out a primary caulking with Philplug by the miners, to conserve air, and then to follow with pointing as the work proceeded, but at a sufficient distance from the shield to avoid cracking?

190. Taking the tunnel contract as a whole, could the average progress in rings per 8-hour shift per face be given? Could also some information be given on progress attained in the secondary lining of the tunnel and concreting procedures adopted?

191. Referring to § 88, pressure grouting might be regarded as being synonymous with boogieing, but Mr Shilston asked whether the Author had meant to imply that pressure grouting with, say, a hand-operated mechanical pump, had been adopted to cure local water seepages.

192. Mr Hedley was to be admired for translating into reality the result of some original thinking on the subject of manhole design. Mr Shilston felt that most probably the Author's curiosity had led him to ascertain whether his boldness had been rewarded in practice. Were there any possible refinements from the operation and maintenance viewpoint which would warrant particular comment?

193. The design of the large-diameter sewers (§§ 38-42), to which the Author had

again clearly given considerable thought, warranted some comment on the decision to include an inner rubber ring at the pipeline joints.

194. In flexible pipelines, the need for a spacer between the spigot end and the back of the socket seemed to be a real one. The presence of a gap had always seemed to Mr Shilston a desirable feature at joints to allow for possible articulation, and to prevent local crushing. On the other hand, the introduction of a succession of gaps in a sewer pipeline had evoked in him a feeling of some concern, because of the undesirable side effects that might be induced. In one respect this might be particularly undesirable where the temperature of the sewage was elevated, as would be the case in tropical countries. It seemed that the Author's internal rubber ring met these various points.

195. Did the Author agree that closer attention than was normally paid during manufacture should be given to ensure that the ends of precast concrete pipelines were truly square to their axis?

The Author felt that the most suitable method of replying to the discussion would be to group the answers to follow the pattern of the Paper.

197. Referring first to the question of the suitability of sea discharge, as mentioned by Mr Harris and Mr Dupree, the design had been produced and the approval of the Ministry obtained before existing controlling legislation had been enacted. The hydrographical survey revealed that a clockwise current was present in the bay which established an outward flow parallel with Breardown even when the tide was rising.

198. While it was not possible to anticipate legislation, the question of disposal to sea was a contentious one and it was considered prudent to incorporate features in the design to allow for rising standards of hygiene. These features included comminutors which besides removing the obviousness of the solids, accelerated the inhibiting action of the sea water; also included were suitably placed joints that would allow diversion of the rising main to a treatment works.

199. The Author's personal view was that discharge to estuarine waters and hydrographic surveys in connexion with them should be made, and examined within the framework of the whole estuary; undoubtedly this was now the policy of authorities exercising pollution control.

200. In reply to Mr Asher, the gradient of the tunnel and main trunk sewers was of the order of 1 in 1250. The decision to provide a gravitational system feeding one main pumping station incurred the elimination of the six existing ones, which had been constructed at random depths to suit only local conditions. The lowest of these controlled the depth for the whole system, but this conformed to the intention of providing fairly deep sewers at the town boundaries for potential expansion or regional development.

201. Mr T. Hedley was correct in his assumption that the system had been designed on a one-year storm but certain refinements had been added as explained by Mr Arnold and Mr Goode. Watkins's R.R.L. method⁴ had not been available when the system had been considered, but the Author felt that re-design using this method and allowing for storage in the sewers, would probably show the system to have a capacity of about a five-year storm.

202. Reference had been made to the shape of the pumping station by Mr Hughes and several other speakers, with particular emphasis on economical advantages to be gained. Tenders were received for a rectangular station with the lowest priced at £186 000, but with one contractor suggesting that his tender of £196 000 would be reduced by £7000 if he were permitted to use a circular cofferdam. After examination this was rejected, a circular station designed, and tenders invited from the two contractors. The original lowest tenderer reduced his figure to £184 000 and the other contractor to £187 000. It appeared therefore that at Weston the economical balance was marginally in favour of a circular station, but the Author felt that the

overwhelming advantages of simplicity and rigidity of support, coupled with clear working space, would influence future designs towards circularity. As the Chairman, Sir George McNaughton, had so rightly said, 'It was not simply a question of the cost of the cofferdam but of having freedom of operation to do the rest of the job.'

203. Referring to the point raised by Mr Hunt and Mr Davis, details of the cofferdam had been shown in a Paper by Packshaw.⁵ Plywood sheeting was placed between the beams and the piles, which in addition to preventing adhesion, bridged across the pan of the piles. The metal cross-halving used to control pile width was shown in Fig. 13. The sinking of the cofferdam had seemed alarming when it occurred, but in fact it was not unusual because the skin friction on the sides was virtually all that prevented it acting as a caisson. As the excavation was made leaving a dumping

FIG. 13: PILE CROSS-HALVING CONTROL

in the centre until the fourth ring beam was cast, one grab was adequate, but this was increased to two during removal of the dumping. Normally in work of this kind a natural division existed with temporary work regarded as contractor's responsibility, and permanent work as engineer's responsibility. It was felt, however, that the cofferdam formed such a large part of the contract and was such a difficult feat in itself that it would be unsatisfactory to accept a tender where the cofferdam might have been given only perfunctory consideration by the successful tenderer. A condition had therefore been inserted giving the engineer the right to approve the design of the cofferdam without accepting any of the responsibility. Admittedly that was rather unfair, but at the time they could not think of any other way of solving the problem without actually designing and incorporating the cofferdam, as Mr Miller had suggested. To accomplish this the piles must take all or part of the load and the Author agreed with Mr Hughes that it was not possible to design a station using sheet piles as part of the permanent structure at the depth involved at Weston. Mr Harris had suggested substituting a concrete wall for the cofferdam assisted by thixotropic materials but the Author felt that the joint between this wall and the base slab, also the buoyancy of the structure, would present formidable problems.

204. The Author said that the major disappointment in connexion with the station was the failure to remove the piles. Piles held on two clutches were most difficult to draw but once the clutch was broken the single piles withdrew easily and were straight and true.

205. He agreed with Mr Miller that the method of billing the cofferdam had been unfortunate, in that an item had been provided for the construction of the cofferdam and the withdrawal of the piles. Whereas the construction could be satisfactorily priced, the withdrawal depended on the number of piles recovered coupled with the time taken. A superior method of billing would have been to include a lump sum for withdrawal and provision for the contractor to give a weekly cost for the hire of the extraction equipment. The number of weeks for which the contractor would be engaged on extraction would be the responsibility of the engineer, and the piles that were withdrawn would become the property of the corporation, for subsequent sale.

206. Mr Oakley had hinted that there would be more trouble with a circular station but the Author respectfully disagreed. For the most satisfactory hydraulic sump conditions the pump suction should be placed on the opposite wall to the entering sewer. In a rectangular station this was difficult to do as the pumps were usually parallel with the long side of the rectangle and there was insufficient width across the sump. The circular shape automatically provided direct entry to the pumps and sufficient width across the sump. The model sump testing had been carried out by the manufacturers as part of the contract, but under the instruction and direction of the engineer.

207. In reply to Mr Morgan, diesel-electric drive had been adopted primarily to maintain flexibility within the station. Up to a few months before the design of the pumping station had been made, the Electricity Board had refused to allow paralleling with the public supply. Fortunately at that time a new chairman had been appointed to the Board, who for years, while working for a large aircraft company, had advocated that paralleling with the public supply should be allowed. It had thus been comparatively easy to obtain permission to parallel this arrangement, allowing the variable load/speed to be carried by the public supply and a full load by the diesels.

208. Mr Fox had suggested the use of axial-flow pumps but to achieve the heads required it would have been necessary to employ either a mixed flow bowl or a two-stage axial-flow pump. Recent investigation by the Water Pollution Research Laboratory had confirmed the widely held view that a considerable increase in the strength of the sewage from a combined system occurred at the commencement of a storm, particularly when the storm followed a comparatively dry period. It was felt that the storm-water pumps would be vulnerable to this storm flush and as the freeway of the storm-water pumps would allow a 5-in. sphere to pass in comparison with the 3-in. sphere of the d.w.f. pumps, suspended pumps would not be truly suitable, as any major blockage, resisting back flushing, could only be cleared by lifting the complete unit. Where, as at Weston, both the head and quantity varied, the most suitable arrangement was for variable speed; the effect of varying the pitch of impeller vanes was to vary the flow at which the best efficiency occurred, but there would be no great variation in the head of the best efficiency point.

209. With regard to the comminutors, they had been mounted over a hole in a suspended floor, this arrangement causing the entering sewage to drop vertically into the sump and thereby had prevented the spinning and weaving of ropes of shredded rags. The problem of sump capacity as mentioned by Mr T. Hedley did not arise, owing to the flexibility of the variable speed pumps. When the inflow exceeded the capacity of the d.w.f. pumps, they were switched off and the flow diverted to the storm sump, where the rising level started the first storm-water pump, whose discharge at this slow speed was slightly less than the combined capacity of the three d.w.f. pumps.

Pumping time was therefore related to the flow in the sewer and not to the capacity of the sump.

210. On the question of the design providing for one pumping station, it should be borne in mind that in dealing with the rise and fall of tide at Weston it was necessary to provide one station solely for that duty. Had they adopted another design they would probably have been faced with the cost of a pumping station at the tidal end, and of a second pumping station further up, with a linking gravity sewer probably laid 10 to 15 ft shallower than the tunnel. In that respect he would draw attention to the final cost figures in § 101 showing tunnel costs comparing very favourably with thick wall pipes.

211. In reply to Mr Arnold and Mr Goode, the construction of the tunnel at a greater depth than originally envisaged had been accompanied by the construction of a lower outfall sewer, thereby avoiding the increased head mentioned except for a short period around high water of spring tides. The Author, if controlling similar work to Weston, would again adopt tunnelled construction, influenced by freedom of choice of depth, economics, and the simplicity of forming the invert after completion of the drive.

212. Replying to Mr Shilston, the Author wrote that local crushing of the segment flanges was caused during early driving by the application of over-severe correction, but this did not re-occur after the modification of the shield (see Fig. 14). The timber packing pieces inserted between the segment flanges materially assisted and prevented damage during circular driving.

FIG. 14: BREAST PLATE FITTED TO SHIELD

213. The influence of the shield rams did not extend more than two or three rings back and caused considerably less damage to the caulking or pointing than did the subsequent reduction in air pressure. The grouting between the outside of the rings and the earth was made at low pressure as no tightening was experienced, but a hand-operated mechanical pump was used to force grout between the lining and the internal face of the segments.

214. Progress varied according to conditions, but excluding extraordinary periods, about $3\frac{1}{2}$ to 4 rings were built during each 8-hour shift.

215. Regarding Mr Dupree's question about the supervision of the work, three engineers and three inspectors had been employed. The contractor had worked three shifts of 8 hours, and when the drive got well in, one visit to each face in each shift was as much as could be done. He had emphasized the question of supervision in the Paper because in compressed air tunnel work, a mild head cold could prevent entry through air locks, and greatly reduce the available supervisory staff.

216. Mention had been made of the outfall, and why steel pipes had been used. The pumping head was a combination of the variable inflow and the variable head, and the pressure head created could not be adequately contained by using the then available concrete pipes. Since that date specially reinforced pipes had been manufactured and if similar conditions existed, it was probable that the use of steel pipes would be reconsidered, and on the basis of economics it might be found desirable to use a specially reinforced concrete pipe.

217. He agreed with Mr Feather that it was probably better to refer to an expansion of the ground than to a heave, but some part of the displacement should be attributed to the natural ground head, as the compromise solution of having a sufficient length of pile to provide cut-off overcame most of the troubles. The major difficulty lay in deciding whether an expansion had taken place, as excavation without regard to this movement resulted in a pipe lower than intended. They had found at certain places where the bottom was particularly soft and where this trouble occurred that there was a sinking of the pipe of as much as 2 in. within a few weeks of completion of the backfilling. Subsequent examination of the tunnel and pipes during ensuing months had revealed no further movement.

218. With regard to Mr Oakley's point, the design of the sewers had been carried out in accordance with the recommendations of Clarke and Young.⁶ Provision had been made in one of the contracts for the laying of a granular bed for the thick wall pipes, but unfortunately this had not been achieved as they had never found a sufficiently satisfactory bottom on which to lay the granular bed. The construction generally adopted was that a bedded flaunch topped with granular fill had been provided for the pipes, with the flexibility of the pipes retained by laying sandbags round the joints.

219. The trench manholes had operated very satisfactorily since being brought into use and the materials used, hot dip galvanized wrought iron for ladders and grilles, stainless steel counter-weight support cables, and cast iron pulleys with phosphor-bronze bearings, had successfully prevented corrosion.

220. In reply to Mr Dyer and Mr Oakley, the design of the manholes had been made to ensure easy maintenance of the sewers and the safety of men engaged in this work, by placing them in the invert of the sewer with direct vertical access to the ground above. With the manhole as designed the man was put precisely where he needed to be and in addition he had a substantial ladder, strings ($2\frac{1}{2}$ in. $\times$ $\frac{1}{2}$ in.) to hold before moving from the ladder, which remained in place while he was working in the sewer.

221. The Author thought that this arrangement must essentially be safer than the normal type of manhole where reliance was placed on benching at the side of the sewer, which involved the problem of climbing down the side of slippery benching to reach the centre of the flow. Removal of a casualty could be made by a direct lift from ground level, and the clear manhole opening was sufficient to allow passage

of a man wearing breathing apparatus. The design shown was suitable for sewers of large diameter, but those below 54 in. would require modification.

222. He agreed with Mr Shilston that close attention during manufacture of concrete pipes should be given to prevent the production of an inferior article. Faults discovered and corrected included eccentric butt and even tack welding of circular reinforcement, the placing of these welds longitudinal in line, incorrect positioning of distribution steel, and puncturing of plastic caps placed over metal spacer stubs when rolling cages from fabrication to spinning shops.

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