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7992 DISCUSSION

Construction of Goscote sewage pumping station

M. L. COOPER

Mr Cooper

Reference is made in § 18 to diaphragm walling as a possible alternative method of forming the cofferdam. During the past few years a number of circular cofferdams have been constructed by using diaphragm walling. To provide an indication of relative costs I wish to refer to a paper by Puller.[9] From this paper and further information provided by Mr Puller, the following would be anticipated costs of a comparable diaphragm wall cofferdam, using 1972 prices.

66. For the diaphragm wall in sands and gravels, the cost would be between £45 and £50/m², whilst in the siltstone costs would be expected to rise to between £80 and £90/m². The actual average cost per square metre of the cofferdam supports as indicated in § 60, was about £34/m². This may be split, as sheet piling costs £25/m² and segments £40/m². Obviously the high inflation during the period since 1972 will have affected these figures considerably.

Mr M. H. Box, Severn Trent Water Authority

The reorganization of the water industry brought me to the position of Engineer to this particular contract in its later stages.

68. This pumping station was built to serve a new sewage works on the site of two earlier sewage works which were running in parallel, and there were several older pumping stations both on this site and elsewhere which this pumping station replaces.

69. The Upper Tame Main Drainage Authority invited tenders for the work, and expected the contractor to put forward his proposals for the temporary works involved. When Lilleys were appointed, Mr Cooper put forward proposals which are the subject of the Paper, and the Authority decided that these were acceptable proposals and they were adopted.

70. Figure 8 shows a plan of the site. One might ask why, having adopted circular temporary works, the Authority did not take full advantage of this and seek to modify the design to achieve cost savings. There are several reasons why this was not adopted, although it was certainly examined.

71. There are several ways in which such cost savings might possibly have been achieved. One of these is the drastic one of completely redesigning the pumping station to the circular form of construction. The second, less drastic, method would be to chamfer the corners so that a pumping station of basically the same shape and dimensions could have fitted within a smaller cofferdam. Fig. 8 shows that in fact this was done in respect of the toe of the floor of the pumphouse. Another way in which cost savings could potentially have been achieved was to use the strength of the concrete portion of

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the cofferdam which was to be left in position to enable the reinforcement in the walls (which was quite heavy) to be reduced.

72. There were two main reasons why none of these approaches was adopted. One is the practical one that on investigation it appeared that no substantial savings would accrue to the Authority from such a redesigning. The other was that the project was fitted into an overall programme to meet tight commitments which the local authority laid down for providing additional sewage treatment capacity to meet housing development, and time did not allow for any major design. Consequently, the works were built basically to the original designs as incorporated at the tender stage.

73. The high quality of the finished work was entirely to the client's satisfaction.

Mr R. D. Taylor, formerly Resident Engineer, Tame Division, Severn Trent Water Authority

With reference to § 61, I should like to ask Mr Cooper to outline the appropriate circumstances in which he would use the segmental ring support again, and to summarize the requirements for the type of ground conditions for which he considers it suitable. This Paper brings out the method of construction used in this instance, and I hope it will help those considering similar work in the future.

75. I would link with my question reference to the site geology (§§ 5 and 6) and to the loss of ground (§ 41). The method of ring building adopted depended on the ground being stable long enough for each segment to be placed. As I recall the circumstances of the loss of ground, it was at about toe-in level of the steel piling, and the concern was whether, with the high external ground water level, there would be a major wash-through of ground along the coal seam level. However, from the type of ground as indicated by the boreholes (Fig. 2), from the conditions of the drive of the sheet piles, indicating the siltstone (§ 30) and from excavation itself being in advance of ring building (Fig. 12), it was thought the loss of ground would be of limited extent and in an emergency could always have been contained from within the excavation, albeit ending temporarily the ring building.

76. As it turned out, I think the ground had stabilized itself prior to the extra struts being placed, and the permanent extra concrete was fairly easily put in to fill the void. I have wondered subsequently whether it would be possible to make provision for dealing with a bad area by incorporating on the outside face of the rings a radiused formed steel plate bolted to the segment through the grout hole, such that it could be forced or drawn down to cover installation of the next ring, and used to hold the face if it were bad, but would be recoverable for reuse if the face were found to hold up on its own. I should be glad of the Author's views on this and his summary of recommendations for using the method again.

Mr W. A. H. Hamilton, Binnie and Partner

The problems of construction described should be of interest to anyone concerned with large pumping stations, including pumped storage stations. Large pump sizes and high speeds economize on plant costs, but do require large positive head on the pump suctions. It is therefore not uncommon to wish to sink pumping stations to levels well below ground. For example, in the recently built Foyers pumped storage stage, the pump turbines are placed in the bottom of silo shafts about 20 m dia. and 40 m deep.

78. The circular cofferdam used at Goscote to enable that pumping station to be constructed appears a good solution to the Author's problem as the contractor. My question which has to some extent been anticipated by Mr Box's contribution, is why, with the need to construct so substantial and elegant a structure for the temporary works, was this same structure not utilized for the outer wall of the pumping station itself?

79. It is not clear what essential additional useful purpose the massive permanent outer walls of the pumping station serve, particularly seeing that in the completed structure most of them are backed by very thick masses of lean mix concrete.

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80. A circular pumping station of the same low level area as the rectangular one shown but with an outer wall of segments similar to those in the cofferdam would appear to have saved something of the order of £½ million on the arrangement actually used. Seepage through the walls might have been a nuisance. Could the Author say how much leakage through the rings occurred after grouting? Could this have been readily reduced if necessary?

81. Uplift is the other obvious problem. This might have been dealt with by underfloor drainage, perhaps discharging into the wet well. Can the Author say whether significant quantities of water came up through the floor? As an alternative to underfloor drainage, perhaps ground anchors might have been used.

82. One suspects, maybe unfairly, that in addition to the identifiable problems from which a circular pumping station layout might suffer, designers may be generally nervous of departing from straight lines and right angles. Could the Author comment on any other aspect of the cofferdam construction which might have prevented its use as part of the permanent works?

Mr W. B. Harris, C. H. Dobbie & Partners

I do not think that a package deal would be appropriate for the design of sewage treatment works and pumping stations of this nature, because there are so many factors to take into consideration in design that it would be very difficult to specify what is wanted in order to obtain proper quotations. However, I am sure they have uses elsewhere.

84. Designers can and should in fact anticipate the method of construction, and a number of circular cofferdams have been constructed now. George Hedley's at Weston was one, and he did another at Newport in Monmouthshire. Another job was in South Wales in sand. This was a pumping station cum preliminary sewage treatment works of about the same diameter but not quite so deep. This was in fact designed and detailed as a circular structure, without really knowing whether the contractor would dewater the ground, use diaphragm walls or perhaps steel sheet piling. In the event, he managed to dewater the ground with two rings of wells, resulting in a very large battered hole and a round concrete structure was built in the middle of it.

85. The Author has referred to clay which was too hard to drive piles through, and I gained the impression that these nodules of clay were isolated. Was it not an outcrop of something more solid beneath? I should like to know the nature of the clay. Further, it would appear that the question of diaphragm walling had been seriously considered, so that I am wondering whether if it was impossible to drive steel sheet piling into the hard clay, how it would have been possible to excavate the trench for the diaphragm walling?

Mr M. Eady, Severn Trent Water Authority

I should like to ask the Author whether this structure is still the largest so far known to be constructed, and accepting that new plant has been developed for this purpose, what in future does he see as the limitations of extending this type of construction even further.

Mr N. R. M. Craigie, Consulting Engineer (ret'd.), New South Wales

The Author has presented a Paper of considerable interest as an example of British practice in pumping station construction in difficult ground. Reasons for the adoption of a rectangular substructure in such ground, particularly when permanent water exists within about 2 m of ground level, however, are not set out in the Paper, and this omission prompts one to ask whether, in the case of the Goscote pumping station consideration was given to the adoption of a circular substructure sunk 'on the kerb'.

88. The latter method of construction is frequently adopted for the construction of both large and small sewage pumping stations in various types of ground (other than

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hard rock) and in the presence or otherwise of groundwater, with very satisfactory results.

89. Circular pumping station substructures are inherently suitable to resist the compressive stresses associated with all structures exposed to external earth or water pressures. When constructed 'on the kerb', concreting operations for the circular shell are carried out at or near ground level and usually above the level of any permanent groundwater. By this method of construction, excavation is kept to a minimum, and the cutting edge of the kerb facilitates sinking when bands of hard materials such as coal, peat and even thin layers of rock are encountered.

90. Sealing of the bottom of the concrete caisson by means of concrete cast in situ or placed by tremie, when necessary, may be simply carried out and a good tight seal achieved.

91. The interior of the circular caisson is divided into dry well and wet well areas by means of radial walls, generally two wet wells and one dry well for pumping machinery being provided ('three-leaf clover' type), or by means of a straight or curved division wall into a dry well and a wet well. The latter is usually divided by a dwarf wall extending above top water level into two compartments to facilitate cleaning of sumps and servicing of pumping machinery.

92. It appears to the writer that the circular pumping station concept, as applied to conditions existing at Goscote could be realized in either of two ways:

(*a*) provision of a circular sub-structure of some 24 m internal diameter divided by means of radial walls into

- (i) a dry well of some 170 m² net area subtending approximately 150° of arc (measured between dividing wall centre lines) for pumping machinery, and
- (ii) two wet walls, each of some 124 m² net area, equipped with one screen, raw sewage storage and sump.

(*b*) construction of a circular well of some 20 m internal diameter divided by a radial wall into

- (i) a dry well of some 170 m² net area subtending approximately 200° of arc, as above;
- (ii) two wet wells, each of some 60 m² area;
- (ii) two separate, identical, circular screen walls each of some 6·5 m internal diameter, one to serve each pump well; and
- (iv) a circular penstock well, also 6·5 m in internal diameter, to direct the incoming raw sewage to either or both pump wells, as required, or to isolate the pumping station in an emergency.

It is here presumed that the Goscote pumping station is operated cyclically, i.e. with alternate filling and emptying periods in the pumping cycle. If the station is operated on the stepless principle, i.e. outflow at all times matched to inflow, the wet wells may be eliminated.

93. One well-known raw sewage pumping station operating on the stepless principle is that constructed some years ago by the Melbourne and Metropolitan Board of Works at Brooklyn, Victoria, Australia.[10] This station comprises two 20 m internal diameter dry wells, two 6·5 m internal diameter screen wells and one 6·5 m internal diameter penstock well, complete with all appurtenances.

94. Could the Author supply the following information:

- (*a*) maximum, average and minimum sewage inflow rates to station;
- (*b*) maximum and minimum discharge rates of each pump, singly and in combination;
- (*c*) effective capacity of wet well between top and bottom operating levels.

Mr G. A. Fryer, C. H. Dobbie & Partners

The Author refers to Black Rock pumping station, but this is neither the only nor the

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largest circular cofferdam in the Somerset area. During the 1970s two large circular cofferdams have been constructed in connection with major tidal outfalls designed for the former Somerset River Authority by C. H. Dobbie and Partners.

96. At Dunball, near Bridgwater, the River Parrett flood relief channel outfall was built in a 43 m dia. cofferdam using 18·5 m long steel sheet piling. Two concrete walings were used: the lower consisted of precast U sections with in situ infill, and the top member was built up with precast laminated slabs. The second cofferdam was at Brean Cross on the River Axe, south of Weston-Super-Mare. In this case the steel sheet piles were 28 m long, the circle diameter was 31·3 m, and three walings were provided. The upper two walings were of fabricated steelwork with drum bracing between, and the concrete infilled U system was again used for the lower waling.

97. Each of the outfall structures was part of a tidal barrier which was completed by extracting the temporary cofferdam piling and redriving it to connect the structure to its adjacent embankments. At Dunball the number of cofferdam piles was less than the number of piles required for the tidal closure and the structure was therefore designed as roughly square in plan to permit extraction of the cofferdam and reuse of all piling. At Brean Cross, however, it was economical to leave the upstream and downstream sections of the cofferdam for inclusion in the permanent works. The structure was designed to suit the diameter of the cofferdam and the sheet piles were thus used as temporary works, permanent cut-off and base slab shutter. Reinforcing bars were welded to the piling and incorporated within the base slab.

98. The extensive temporary works were required at each site because of the large tidal range combined with estuarine silt ground conditions, but the overall cost of the works was considerably reduced by the incorporation of cofferdam materials within the permanent structures.

Mr Cooper

I would like to thank all those who have contributed to the discussion and in particular **Mr Box** for their comments.

100. **Mr Taylor** asked in what circumstances it would be appropriate to use the precast concrete segmental supports in future work. It has been shown that in 1972 the segments were more expensive than steel sheet piling and less expensive than diaphragm walling. Economy therefore suggests that the system should be considered for a supported excavation where it is not feasible to drive sheet piles, whether for environmental reasons or because of ground conditions. The cost of steel in particular has escalated since 1972 and the relative costs of sheet piling and segments may now be different.

101. Segmental shaft linings are best used in ground which is stable enough to stand to a vertical face whilst the segments are being built. The method is sufficiently flexible to cope with local soft spots and I think that at Goscote it would have been possible to overcome difficulties created by soft areas even more extensive than those encountered. The method does not necessarily break down in unstable ground since the ground can often be improved by geophysical methods, or compressed air can sometimes be used on smaller diameter shafts.

102. As suggested, auxiliary supports can be used. Mr Taylor's suggestion of using a purpose-made steel backing plate is worthy of consideration. In excavating smaller shafts, a steel 'sinking skin' incorporating a steel cutting edge and jacked down from segments previously constructed has sometimes been used. Naturally, the use of any of these additional measures increases costs.

103. I should like to refer to **Mr Hamilton**'s first question, namely, why was it necessary to produce such a massive structure purely as temporary works which were not utilized in the permanent works. There is not a straightforward answer to the question. I think it is bound up to some extent with the relationship between the designer and the contractor in the method that civil engineering is organized in this country. If the designer at the initial concept stage had considered that it was necessary

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to construct the pumping station in a circle, then presumably he would have designed a pumping station on a circular plan.

104. I understand that the designers preferred the rectangular layout as being more appropriate to the layout of the mechanical equipment than a circular one. It may be, therefore, that the savings which could have been effected in the cost of the construction would have been partly offset by the additional costs of the mechanical equipment if a circular layout had been adopted.

105. Traditionally it has been considered proper by designers to leave the question of the design of temporary works to contractors on the ground that if the designer specifies a method of construction, higher costs result, and I think this is the background to the design of this pumping station. As **Mr Box** said, it may well be that if the construction method and the permanent works had been integrated, then cost savings would have resulted. Possibly here is a case where the package deal type of contract might have offered savings.

106. Going on to Mr Hamilton's second question concerning seepage through the segments, caulking grooves were incorporated in the segments, but when the completion of the segments was in sight it was realized that the seepage through them was relatively small, and since they were, in effect, temporary works, it was decided to economize and to omit the caulking. If there had been a good reason to do so I am sure the segments could have been made substantially watertight by caulking. A large proportion of the water which was made at the segments came from the joint between the sheet piling and the segments. It tended to build up at the top of the segments and run down them, but the quantities of water were not significant, and a normal 75 mm pump in the sump coped adequately with any water that was made.

107. On the question of uplift, a certain amount of water was found in seams at the base of the pumping station, but again it was a relatively small amount.

108. As to the final question on whether there was any other aspect of the design preventing the use of segments in the permanent works, I consider that this form of construction could well be used in permanent works preferably in conjunction with an in situ lining. Before this contract the method was not available, since it was developed as a solution to the problems in this particular contract; now it is available and should be used when economical.

109. In reply to **Mr Harris**'s question in connection with the description of hard clay, the material I was referring to is weak grey argillaceous siltstone. This is shown in the boreholes in Fig. 2 and referred to in the section of geology. The siltstone was part of the coal measures and I understand that this stratum occurs frequently in conjunction with coal measures in that part of Britain. It is referred to as fireclay by the mining community.

110. In fact the hard inclusions occurred at random, and it was by no means possible to predict their extent. They were noted and emphasized by the pre-contract site investigation, so that everybody was fully aware of their existence. In fact, I also mention in the Paper that the toes of the sheet piles driven at the upper level were extensively buckled in certain areas, confirming that there were problems in driving sheet piles.

111. Mr Harris asks if it was not possible to drive sheet piles, would it have been possible to excavate a trench using diaphragm walling. I am not a specialist in diaphragm walling, but I understand that the diaphragm walling grabs could penetrate relatively soft rock of this nature. However, progress would be slow, and hence inflate the cost of the diaphragm wall in the siltstone area.

112. In reply to **Mr Eady**, so far as I know, this remains the largest cofferdam constructed with a precast concrete segmental lining. As is well known, several cofferdams have recently been constructed to larger diameters using diaphragm wall linings.

113. It would seem feasible that larger diameter shafts could be constructed by this method in suitable conditions. Design of a large diameter segmental lining should be treated with caution, however, since conditions of elastic instability can arise. When

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the thickness of the segments becomes small in relation to the circumference, failure can take place by buckling of the circle into an elliptical shape. Each new design would have to be developed individually.

114. I was pleased to read **Mr Craigie**'s observations from Australia. First of all I would like to say that the Paper was concerned with the construction of the work and that I have little knowledge of the details of the design of the permanent works.

115. Precast concrete segmental shafts have frequently been constructed in conjunction with a cutting edge and kentledge loading. This was one of the alternative methods available, as well as the possibility of an in situ concrete sinking caisson.

116. It should be remembered with this cofferdam, that in the first place its diameter was large in relation to its depth and secondly that the impermeable layer beneath the water-bearing sands and gravels was known to have a steeply sloping surface. The combination of these two factors meant that if the cofferdam had been constructed by sinking, there would have been a serious risk that it could develop a tilt during sinking. It was clear that any measures necessary to correct the tilt would have been expensive. The system was therefore not pursued.

117. In reply to Mr Craigie's request for information, the following design data have been supplied by Mr Eady:

(*a*) at the intitial stage referred to in the Introduction of the Paper, the maximum sewage inflow is 1700 l/s, minimum sewage inflow is 150 l/s; at the final stage there will be a maximum sewage inflow of 2900 l/s;

(*b*) the two small pumps each have a range from 100 l/s to 230 l/s, the four large pumps from 250 l/s to 680 l/s; the control system is arranged so that as the flow increases, the second pump cuts in when the first reaches 90% of its capacity and so on until all pumps are running; when the final phase of construction is carried out at a future date, the two small pumps will be replaced by two pumps similar to the present large pumps; excess pumping capacity has been provided so that one pump will be on standby at all times;

(*c*) the effective capacity of the wet wells is 300 000 l. This provides some margin in the event of a mechanical failure.

118. The contribution from **Mr Fryer** records useful practical information on the construction of two large circular cofferdams constructed by using driven steel sheet piling.

References

9. Puller M. J. Economics of basement construction. *Diaphragm walls and anchorages*. Institution of Civil Engineers, London, 1975, 171–179.

10. Davy W. J. and Bird A. W. Functional design of the Brooklyn sewerage project. *Civ. Engng Trans. Instn Engnrs Austr.*, 1961, 73–83.

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