Proc. Instn Civ. Engrs, Part 1, 1976, **60**, Nov., 699–710

7880 DISCUSSION

Development of Edinburgh's sewage disposal scheme

A. S. CROCKETT & J. DUGDALE

Mr H. R. Oakley, J. D. and D. M. Watson

This valuable Paper would have been of even greater interest if attention had been drawn to points of difficulty. I cannot believe that a scheme of this magnitude will have gone forward without problems and I invite the Authors to indicate some of the points, large or small, where they feel they have learned and engineers in turn can learn from their experience.

64. When the hydrographic survey was executed, one of the tasks was to examine the degree of treatment which would be appropriate to different lengths and positions of outfall. The conclusion was reached that the cheapest scheme in terms of capital and operating costs was that involving little or no treatment, but having regard to the characteristics of the estuary and to the proximity of this beautiful city to the sea, it was decided that primary treatment should be provided. In the course of making this comparison it was necessary to make estimates of cost and it is of interest to compare the costs set out in the Paper with the estimates. The estimated cost of the outfall, £3·1 million, compares with the contract value of £2·9 million; the estimate for the treatment works was £5 million compared with a total cost of £6·7 million and may reflect the difficulty of estimating the cost of construction on such a difficult site.

65. It is apparent that a scheme of this magnitude requires the closest consideration, and the City Council did not embark on such a large expenditure without having had the City Engineer's proposals independently reviewed; my firm was able to confirm the necessity for the scheme and to endorse the City Engineer's outline scheme in almost every particular. Nevertheless I still have three slight reservations. One is on the question of the basis of design of the interceptor sewers. In § 17 there is reference to overflow setting at each point of intersection which has been calculated in the 'standard' manner. I take the view that for schemes of this nature where storm overflow discharges to the sea or to the estuary, the basis of design could be less than the conventional $6 \times$ dwf, and I should be glad if the Authors could expand on that particular point.

66. Secondly, I question the choice of circular as against rectangular sedimentation tanks for the sewage treatment works, and I am not convinced as to the merit of the unconventional design of the tank inlets. Third, and more important, is the question of sludge disposal.

67. The Authors have described in the Paper why they felt that crude sludge disposal was acceptable, but I believe anaerobic digestion before sea disposal to be desirable for several reasons. First, to control smell; I note with interest the steps which the Authors have taken to combat offensive odours during the storage of crude sludge prior to shipment. Second to reduce floatables, particularly of greasy matter, which are of

Paper published: *Proc. Instn Civ. Engrs*, Part 1, 1976, **60**, Feb., 53–78.

Downloaded from http://ftp.nowpublishers.com/jpric/article-pdf/60/4/699/2570518/iicep_1976_3375.pdf by guest

overriding importance aesthetically. Third, the introduction of biological sludge treatment provides opportunity to give warning against the accidental discharge of toxic or intractable wastes, and assurance that the discharged solids will not be ecologically damaging.

Mr A. Shilston, Consulting Engineer

On ground exploration (§ 14) could the Authors say at what approximate spacings the investigating boreholes were put down on the interceptor sewer lines, and on the line of the sea outfall, distinguishing between the two? In § 25 there is reference to the remarkable range of ground conditions met on the sewer tunnel drives. Having regard to the task of driving substantially rock tunnels for sewer conduits and on the land routes below residential properties in built-up areas with little cover, the task of devising an appropriate contractual framework within which to undertake the construction of the tunnels must have been formidable.

69. A private Act of Parliament was needed to protect the powers for construction of the sewer networks, and put at risk by the Sewerage (Scotland) Act, 1968. Was such a private Act needed specifically to allow the driving of tunnel excavations in built-up areas under property? Could the Authors enlarge on the need for this private Act?

70. On the subject of intercepting sewer and effluent outfall contracts generally, were target cost contracts considered? Were restraints imposed by the contract machinery to regulate blasting periods in built-up areas, and was 24 h working in the tunnels precluded for public relations reasons?

71. How has the public reacted to the construction work, and what has been the procedure for investigating property damage claims, real or imaginary?

72. Since no details have been given in the Paper of the tunnel linings, can it be assumed that lining type was selected on site from provisional design details having regard to ground conditions revealed on excavation? What procedure has been adopted for filling the tunnel overbreak cavities, and making the linings watertight? Finally, on the sewers section, what pattern of access manhole spacing has been adopted?

73. Turning to the sewage treatment plant, § 35 states that there are four very large storm tanks. Could their dimensions please be indicated.

74. The provision of mechanical and electrical plant apparently has been arranged under principal contracts and not nominated subcontracts. Do the Authors believe on balance that the preferable method is to make the Resident Engineer directly responsible for organizing and supervizing the installation of mechanical and electrical work, rather than place that responsibility on the main works civil engineering and building contractor through the nominated subcontract procedure.

75. What is the sludge storage capacity of the site storage tanks and the sludge holding tanks at Leith Docks? One sludge disposal vessel is being provided at a cost of over £1½ million. What contingency plan will come into operation if that vessel is inoperative? In 1965 a relatively new sludge vessel of the Greater London Council was involved in a collision in the Thames and it capsized and sank.

76. Turning to the marine effluent outfall and referring to § 50, I would be hesitant about installing 20 effluent diffuser pipes ahead of a tunnel outfall drive. The tunnel might never have been completed due to adverse ground conditions, or, perhaps, lack of availability of funds during financial crisis conditions. The technical literature recorded in 1970 and 1971 the building in the British Isles of a maritime sewage outfall rock tunnel about 2000 m long.[1] Work had to be stopped on that tunnel well before the designated discharge point had been reached due to adverse ground conditions. The outfall eventually terminated in a substantial length of submarine pipeline laid in a shallow trench on the sea bed. So the obvious point is that whilst there were no doubt compelling reasons why the diffusers were sunk ahead of the main tunnel drive, a cautionary note should be sounded as to what might have happened.

77. At a national conference in September[2] 1975 a speaker said he was responsible for the maintenance of several long sea sewage outfalls with diffuser outlets. The operating

Downloaded from http://ftp.nowpublishers.com/jpric/article-pdf/60/4/699/2570518/iicep_1976_3375.pdf by guest

maintenance costs in cleaning out the diffuser ports were substantial, as the work all had to be done by divers, and suitable weather conditions for diving also had to prevail. I mention this again as a cautionary note for investigation by future designers. Operation can never be divorced from design in the conception of public health engineering schemes.

Mr D. G. M. Roberts, John Taylor & Sons

While wishing to congratulate the Authors on the technical content of their Paper, I regret that they have not elaborated on the reasons for adopting a treatment works as well as the 3 km long sea outfall—and one which was over 3 m in diameter and constructed in rock. It seems an unusual combination.

79. Of the total cost of £18 million, no less than £8 million were spent on the treatment works and associated sludge disposal vessel compared with £3 million on the outfall and £7 million on the intercepting sewers.

80. The estuary is over 30 km wide; the discharge point is at a depth of 8 m at low tide, and gives a minimum dilution of 20:1, while dissolved oxygen at the point of discharge is stated to be 85% of saturation under the worst conditions. The effect of primary treatment is to reduce the BOD load by about one-third, so the effect of the treatment works is to reduce the oxygen demand from that of a population of 600 000 to a population equivalent of 400 000. If it is possible to dispose of the sewage from an equivalent of 400 000 people safely at this point, I am surprised it is not possible to dispose of the sewage from 600 000 people, under the environmental conditions pertaining.

81. I should like to ask first, how different would have been the results if crude sewage instead of settled effluent was discharged at the point of discharge of the long sea outfall. Secondly, if this was thought to be unsatisfactory, how much further out would the Authors think they would have needed to go to obtain a satisfactory point of discharge, bearing in mind that the tunnel is costing about £1 million/km and that for an extra £2 million or £3 million they could have gone out another 2 km.

82. Thirdly, was the decision to adopt a treatment works at a cost of £8 million as well as a long sea outfall reached on engineering or political grounds?

83. The Authors have referred to marine biological investigations which have been started. The results of other similar work carried out in Liverpool Bay to assess the effect of the discharge from a population of some 100 000 people served by the North Wirral Long Sea Outfall are to be published. This effluent discharged into some 3 m of water at low tide, but even so the discharge was found to have virtually no effect on the marine life, and it was impossible to detect the presence of the sewage by chemical means within 200 m, and by bacteriological means within 400 m respectively from the point of outfall.

Mr J. M. Pettigrew, Scottish Development Department

I have sympathy with the remarks on associating a large sewage treatment works of this type with disposal by a long sea outfall. I think I should like to extend the remarks made to ask the Authors if they would say something about the philosophy behind the adopted method of treatment in the circumstances surrounding this particular scheme for Edinburgh.

85. Not many civil engineers have the privilege of ordering a ship, especially one of such a size. Perhaps the Authors would say something of how they decided what they wanted, and how they translated what they wanted into a specification.

86. A great deal of expense was met in constructing the bund behind which the land was to be reclaimed. Was thought given to enlarging the bund to provide docking facilities for the sludge ship, perhaps saving the expense of moving the sludge from the sewage works to the docks and dock charges?

Downloaded from http://ftp.nowpublishers.com/jpric/article-pdf/60/4/699/2570518/iicep_1976_3375.pdf by guest

87. The practice of digestion before disposal at sea is one which is carried out in some places, but a great deal of consideration would have to be given before embarking on it when finance is so difficult to come by.

88. To the east of Edinburgh there is a productive coalfield. May I ask whether the mineral abstraction extends as far west as the line of the outfall tunnel? If so, what regard was taken of it?

89. In Glasgow the method of sludge disposal is by means of ships to the Firth of Clyde, but as well as disposing of Glasgow's sludge, sludge is collected and disposed from many other authorities. Will these benefits will be available to the communities within reasonable distance of Edinburgh?

Mr P. A. Banks, John Taylor & Sons

It was stated that the ecological survey was to be confined to the south coast of the Firth, and could not be done on the northern side. If it was necessary, why did the northern side have to be excluded?

91. In the Paper, it is said that the location of sludge dumping some 68 km out to sea was at the suggestion of the Department of Agriculture and Fisheries for Scotland. I do not know whether DAF Scotland is as difficult as MAFF in England, but I would be interested to know if they produced any scientific data suggesting that this was the best place, and that the original site was unsuitable.

92. The boat presumably will take at least 12 h for the round trip, if not longer. How often is it proposed that it should sail, and with what crew? Was any consideration given to the possibility of asking for tenders for a sludge disposal service from shipping contractors as opposed to building Edinburgh's own boat? What sludge storage is there available at the site against bad weather and ship breakdowns or refitting? Is there any possibility of using the storm tanks as sludge storage tanks when the boat cannot sail or will the sludge go out through the outfall?

93. Whilst referring to the storm tanks, I should also like to know what is the size of the storm tanks and their capacity. One might also perhaps ask whether a sea outfall of this length necessitates the use of storm tanks.

Mr J. Buchanan, Sir Robert McAlpine & Sons Ltd.

The difficulty of designers is well seen by the conflicting advice already received, on the one hand to extend the tunnel another 3 km, but accompanied by the warning that they might not even reach 1 km. In that respect I was wondering whether the present length of tunnel is what was originally planned, or whether it was related to the revised depth of tunnel.

95. There is clay at the end of the tunnel; might this have encouraged the Authors to adopt the push-up system, with just one shaft at the end of the tunnel and a seabed pipeline? This would have reduced the length of the tunnel by the 800 m where there are diffusers. The optimism in sinking the diffuser shafts early was shared not only by Edinburgh, but by the Portobello outfall, so the Authors are not alone in their feelings.

96. Is there any likelihood of an improvement of the environment around Cramond and, indeed, anywhere else? Were there any complaints on the ground that some of the frontage to the river was being removed? With regard to § 31, there is expected to be a reduction in the surface and ground water to be taken into the sewers. I should like to have some amplification of that. Were the designers content that the existing tributaries were sufficient, or have any provisions been made for future connexions.

Mr P. H. Austin, John Taylor & Sons

I notice that several siphons are to be constructed or have been constructed. I should be grateful for further information about these. In particular could the Authors say what their length is, and whether any provision has been made for their inspection, cleaning, if necessary, and any necessary maintenance once they are in service.

Downloaded from http://ftp.nowpublishers.com/jpric/article-pdf/60/4/699/2570518/iicep_1976_3375.pdf by guest

Mr M. Lonsdell, *Consultant, Venezuela*

With reference to the interceptors, I would like to know if any special ventilation facilities were incorporated. The Authors state that the downstream end is sealed by a siphon and I assume the existing sea outfalls are submerged at the seaward end, so I wonder how air will escape during thunderstorms.

99. Would the Authors consider that any worthwhile improvement in the water quality of the estuary could be obtained by including some means of monitoring and controlling the volume intercepted, at least through the four larger connexions? From the information in the Paper it seems that the overflows have been set at about 6× future dwf, or about 8 × present dwf. Bearing this in mind, and the fact that a sharp thunderstorm very rarely covers the whole drainage area but can produce highly polluted runoff after a prolonged dry spell, it would seem that some advantage might be gained by 'playing tunes' with the system. The treatment works are blessed with a very comprehensive and sophisticated monitoring system, but as is so often the case, the works manager has no control as to what enters the works.

100. Referring to the sedimentation tanks, the use of air lifts on the sludge withdrawal system is interesting. Perhaps the Authors would explain their adoption rather than the normal hydrostatic pipework, sight hose and siphon.

101. The use of a tractor mounted squeegee in the storm tanks is an interesting example of a return to an older, less sophisticated method, probably very economical on capital.

102. Regarding the outfall, perhaps the Authors could give more details of the diffusor heads, especially with reference to materials selection and the possibility of damage by shipping.

103. The Authors have presented a comprehensive paper on a very interesting scheme, and it is to be hoped that in the future there will be a further paper, say in ten years' time, on the ecological impact of the scheme.

Mr Crockett and Mr Dugdale

Mr Oakley raised the question of the problems which had been encountered during construction. There have indeed been many problems, some expected and some arising without warning. On the broad aspect of administration, the work has been carried out in a period of general change. On the financial side, there has been heavy and varying inflation and the restriction of loan sanction to go ahead with the final contracts. On the industrial relations front, there have been the inevitable strikes affecting progress both directly and indirectly, and a marked change in the independent attitude of the construction worker and in his willingness to tackle a range of jobs which hitherto has been such a strong feature of the heavy construction industry.

105. On the subject of contract procedure, we have had contracts on both fixed and variable basis on the fourth and fifth editions of the ICE Conditions of Contract and others on those of the IMechE and RIBA. In addition there has been the introduction of the productivity deduction and the responsibility for attempting to ensure that contractors are complying with the counter-inflation legislation. Added to these changes and the related problems, we have had the experience of local government reorganization.

106. Undoubtedly the most numerous and difficult technical problems have arisen during construction of the tunnels through the built-up areas. Many of the situations had been broadly predicted from the ground exploration, but it is only when construction is under way that, for example, the ability or otherwise of the ground above tunnel level to hold the compressed air becomes known. The use of explosives will always, we feel, be accompanied by uncertainty in variable ground. The different types of ground lead to varying attenuation of the shock waves from a blast and it is never clear at which point vibrograph readings should be taken to give the maximum permissible weight of charge. Buildings also vary widely in their susceptibility to damage from vibration.

Downloaded from http://ftp.nowpublishers.com/jpric/article-pdf/60/4/699/2570518/iicep_1976_3375.pdf by guest

107. Two examples might be cited where the difficult conditions led to actual damage. The first concerned a collapse in the roof of the tunnel excavation which caused subsidence to a building over the line of the tunnel. The primary cause of the collapse appeared to be a broken drain serving the property which had been leaking for some time and which had caused saturation of the ground material to a fluid state which led to the collapse into the tunnel excavation. The second instance occurred at a critical point where the tunnel was passing between two blocks of semi-detached bungalows with a cover of only some 3 m over the crown. At this point a ridge of very hard dolerite was found to protrude above the invert and the tunnel was already under compressed air for the support of the cover material. Explosives were essential for the removal of the dolerite, and the resulting vibration and the consequential delay whilst this operation was carried out resulted in subsidence of one bungalow in each pair to a degree that made demolition and rebuilding necessary. Many other instances could be described but we are aware that similar instances may well occur in built-up areas elsewhere and they are largely unpredictable. However, few urban areas in the country have geological conditions which are so complex and varied.

108. Moving to the treatment works, one aspect of design of the bund wall subsequently proved to be defective. Since no cut-off was included in the wall, it was considered as permeable and the facing blocks to seaward were bedded on gravel and had open joints for the purpose of releasing at the lower states of the tide the water which had passed through the wall to the reclamation area at the higher states of the tide. During a period of rough sea conditions with waves of exceptional height, the waves were running up the face of the wall and water was passing through the open joints. However the wall hearting and demolition material backing to the wall had consolidated far more quickly than expected and the water passing through the wall was apparently not rapidly dispersing but was contained just behind the facing blocks. As the waves fell back, the water so held could not escape quickly enough through the open joints and the back pressure on the blocks caused a number to be dislodged. All the blocks placed up to that time were then removed and rebedded on concrete and the wall has now stood the test of time without further trouble.

109. A problem which might have developed but which was avoided is worthy of mention. This concerns the deterioration of joint sealing compounds in concrete structures where exposed to sewage. When this subject was highlighted in *New Civil Engineering*,[3] a series of tests was initiated in a live sewer. The tests clearly showed which of the compounds 'broke down' on this exposure and which retained their texture, and on this basis the choice of compound was made.

110. Turning to Mr Oakley's specific points, the first concerns the overflow settings at the points of interception of the flows in the existing sewers. These were calculated on the formula given in the Final Report of the Technical Committee on Storm Overflows and the Disposal of Storm Sewage which is now regarded as standard practice. There is a considerable variation in the proportions of domestic sewage and industrial wastes in the dry weather flows of the individual sewers being intercepted and the calculated settings varied from 4·05 × dwf to 6·0 × dwf, the average for the whole city being 5·0 × dwf. To reduce these settings was not considered acceptable in the circumstances for reasons of bacterial contamination from discharges through the storm sewage overflow pipes close inshore.

111. The choice of rectangular or circular sedimentation tanks depends largely on individual preference. Restriction on space is frequently an important reason for choosing the former type but in our case, given that we were compelled to resort to land reclamation for the treatment works, the angular configuration of the reclamation site resulted in ample area being available. The main aim was the removal of sludge which was uniform in consistency and had a moisture content of about 95%, all as a one-off operation without the need for subsequent dewatering. With the high sewage flow involved, the tanks would be of very large size if their number was to be kept within reason. From these considerations, we decided that circular tanks with air-lift pumps

Downloaded from http://ftp.nowpublishers.com/jpric/article-pdf/60/4/699/2570518/iicep_1976_3375.pdf by guest

for sludge removal, each of which would deal with an annulus within which the radial flow would give a consistent sludge, offered the best solution. So far as the tank inlets are concerned, we are satisfied from the results of the research work, which involved the use of actual sewage in a one-sixth scale model tank, that the flow will move radially without bias in any particular direction and that the solids removal efficiency will be high. This arrangement will however be expensive in hydraulic head loss, amounting to about 1·5 m at peak flow.

112. The question of the condition of the sludge for sea disposal was given a good deal of thought and an attempt was made to consider the matter objectively rather than simply to follow the usual practice of introducing digestion before disposal, since there is no fundamental reason why digestion must be carried out. The intention finally evolved to discharge the sludge in the raw state some 24 km east of the Fife coast whilst the ship is in motion, to take advantage of the significant dispersion created by the ship's propellor and of course to spread the sludge over a greater area. A full cargo of 2300 t will be discharged over a travel distance of some 10 km, which perhaps puts the matter of loading into perspective. We do not consider smell to be of any consequence at this loading and in an area so far from the coastline. The breakdown of grease by digestion would certainly be an advantage in the rate of dispersion and diffusion, but again at the loading proposed the advantage would be minimal. Regular testing of the sludge produced at the works will be carried out and any containing a high toxic content through accidental discharge of waste to the city's sewers can be readily isolated in one of the site storage tanks. The point might be made that, if digestion were included, the first indication of a high toxic content might only come with the complete failure of the digestion process.

113. The first of **Mr Shilston**'s questions referred to the ground exploration. Because of the wide variation in ground conditions over the interceptor sewer routes, the placing of boreholes was not to a predetermined spacing but was organized on a day to day basis to take account of what had been revealed to date and what could be broadly predicted for the conditions ahead by conjectural sections drawn up by the Institute of Geological Sciences from the information held in their records. The actual spacing therefore varied widely, being on occasions down to 15 m. The offshore work was carried out with a rather different approach, as we did not have the advantage of preliminary information. The sequence began with the sinking of boreholes, initially at 200 m spacing to give the general picture; intermediate boreholes were then sunk to reduce the spacing to 100 m. Finally, further boreholes were placed to reduce the spacing to 50 m over certain areas where discontinuities and uncertainty had been revealed.

114. All contracts for the interceptor sewers and for the effluent outfall have been of the Bill of Quantities type, with the issue of the tender documents to selected lists of contractors. Because of the difficult ground conditions, substantial provision was made for the use of explosives and for operation in compressed air and the opportunity was given for contractors to submit proposals for special techniques for construction through sections of special difficulty. The effluent outfall documents allowed the offer of an additional tender for the work based on an alternative construction and in the event such an alternative was accepted.

115. The private Act of Parliament was necessary principally to secure the powers for construction of the interceptor sewers as a complete system. At the time the Bill was promoted in 1970, the Sewerage (Scotland) Act 1968 was on the statute book although not in force, and it included provision for appeal, by any owner or occupier of land through which a sewer was to pass, to the local Sheriff and not to the Secretary of State. It was conceivable therefore that an appeal concerning an individual property could be considered in isolation and if upheld could have had a very serious effect on the interceptor sewer system as a whole.

116. Construction over the full 24 h was permitted on the interceptor sewers; the use of explosives was allowed initially only between 7 a.m. and 11 p.m., but further restricted on later contracts to between 8 a.m. and 10 p.m. In the early stages of

Downloaded from http://ftp.nowpublishers.com/jpric/article-pdf/60/4/699/2570518/iicep_1976_3375.pdf by guest

construction through the built-up areas, there was an understandable reaction from the people in the areas concerned to the inevitable disturbances through operations at the working shafts and from vibrations caused by the use of explosives, and there was general apprehension at the risk of damage to property. Special efforts were made from the beginning to inform people of the intentions of the construction and there was a gradual acceptance of the work as vital to a scheme which was welcomed by most people, particularly in these areas close to the coastline. To safeguard the interests of the owners of property and to help with the assessment of claims for damage, private firms of surveyors were engaged to carry out inspections beforehand of those properties which might be affected and 'after' inspections of those properties in respect of which claims for damage were made.

117. With regard to the tunnel linings, the primary structural lining for the most part has been formed from standard precast concrete segments. We have considered at length this question for tunnel work generally, and we have serious reservations about carrying out specific lining design on the basis of borehole information in ground which is subject to rapid change. The general use of standard linings probably results in overdesign for most of the lengths, particularly those in rock, but the standard segments are relatively cheap. The cavities resulting from overbreak were grouted up in the usual way and the tunnels made watertight by caulking of the joints between segments and fitting of grommets to the segment bolts, again in the usual way. The secondary lining has been formed with in situ concrete. The spacing of access manholes averages 250 m on the larger sewers constructed to date.

118. On the sewage treatment works, each of the four storm tanks is 100 m × 30 m with a floor slope of 1 in 100 towards the inlet, and the average water depth is 3·3 m.

119. It was considered on balance that the larger sections of mechanical and other plant should be the subject of separate contracts to continue the direct contact between the design engineers or resident engineer and the manufacturers to deal with the many adjustments and modifications which invariably become necessary. Also, due to the pressure with the programme for completion of the scheme, design work to finalize the more complex contracts such as the electrical distribution and the control and instrumentation contracts continued for some time after the civil work began.

120. The capacity for sludge storage amounts to 5150 m^3 in the site tanks and a further 2220 m^3 in the holding tanks alongside the berth for the sludge vessel. Related to the expected initial yield, this represents about 5½ days storage. It is intended to have available a standby service from a commercial firm in the event of the sludge vessel's being laid up for major overhaul or following a serious breakdown. Preliminary discussions have been held with another authority with the intention of entering into a joint arrangement with a private firm for the standby service.

121. The sinking of the diffuser feed pipes in advance of the effluent outfall tunnel has been questioned on the grounds that the tunnel might not have been subsequently completed, for technical reasons or through financial restriction. Whilst it is obviously prudent to avoid overcommitment in these uncertain times, in our case nothing significantly less than the 2·8 km tunnel with the diffuser system would have been acceptable. The profile of the bed of the estuary and therefore the cover over the tunnel was accurately known and most of this cover was composed of rock or consolidated glacial deposits with very little taken up by uncertain alluvial material. There has never been any doubt in our minds that it was technically possible to complete the tunnel, the only question being the degree of difficulty which might be experienced. With regard to non-completion of the tunnel through financial restriction, the situation would need to be extremely serious for money to be withheld for completion when some £20 million had been spent on the remainder of a scheme which could not be put into operation because of the lack of the vital effluent discharge arrangements. Sinking of the diffuser feeds could not have been carried out along the line of the tunnel after its completion because of the risk of bursting of the rock during drilling due to the high hydrostatic head and, of course, the problem of water entering after breakthrough.

Downloaded from http://ftp.nowpublishers.com/jpric/article-pdf/60/4/699/2570518/iicep_1976_3375.pdf by guest

122. With regard to maintenance of the diffuser system, the design of the ports in the diffuser heads has been made as simple as possible with the port linings of glass reinforced plastic to give a reduced adhesion for marine growths, and the required frequency of maintenance is expected to be very low.

123. In reply to **Mr Roberts,** we would emphasize the unusual nature of the body of water into which the discharge is to be made. Whilst we have stressed that the estuary ought more sensibly to be considered as a large inlet of the sea, there remain the disadvantages of reciprocating and rotational movement of the water under tidal influence and the currents are relatively weak. It should not therefore be regarded as an area of open sea where a sewage disposal problem usually resolves itself into a question of how far out one ought to go before the increasing depth, increasing current strengths and reducing risk of return to the coastline give acceptable conditions for a crude sewage discharge. In our case, the capacity of the receiving waters to accept a discharge of crude sewage is not proportional to the length of the outfall as is so often the case with open sea situations. It was only after the most detailed equation of the loading with the capacity of the estuary waters that the decision was taken to combine a primary treatment works with a long outfall. It should go without saying that the scheme was based solely on engineering and scientific judgement.

124. There will undoubtedly be some detectable ecological improvements when the scheme is implemented. At some areas along the coastline, the present flora and fauna indicate heavy pollution and the pathogen *Salmonella* has been found in a number of cases in the tissue of shellfish, which tend to accumulate bacteria through their filter feeding mechanism.

125. **Mr Pettigrew** asked about the philosophy behind the treatment intentions of the scheme. Some thoughts have already been expressed but the subject can perhaps be dealt with now in a logical manner. For Britain as a whole, it is seen that the sizeable communities located on estuaries are generally sited some distance up the estuaries and on the narrow reaches. The practice there has generally been to aim for biological treatment and we consider this to be the proper course. On the other hand, the sizeable communities sited on the open coastline are usually served by long sea outfalls with discharge after only preliminary treatment. Again we would consider this to be acceptable in principle, provided always that the efficacy has been justified with a detailed hydrographic survey. In the case of Edinburgh, we have a unique situation with a sizeable community discharging to a large inlet of the sea. The initial indication was that some degree of treatment beyond the preliminary stage but less than to the biological stage might be adequate. The subsequent investigation and hydrographic survey showed that the apparent large purification potential of the offshore waters was sharply limited by the form and magnitude of the currents and by the shallow depth. Further detailed work showed that an outfall starting from a convenient point on the coastline and of a length to the limit considered practicable would be acceptable only if combined with primary treatment for the removal of the heavier fraction of the solids in suspension. The provision of primary treatment would introduce the sludge disposal problem but open sea conditions with the deeper water and stronger currents were within reach of a sludge vessel for the disposal of that component of the sewage.

126. The decision on the sizing of sludge vessel was not straightforward. Many authorities round the Forth estuary and inland had expressed interest in and varying degrees of enthusiasm for making use of the disposal facility. There was difficulty, however, in obtaining firm decisions because of the impending reorganization of local government. Eventually the capacity of the vessel was fixed to deal with the likely sludge yield from the works in the proposed Lothian region, operating on a basis of five sailings/week. Should there be a further demand for the facility, the number of sailings could be adjusted to meet this demand. The procedure for the actual construction of the vessel was to draw up a broad performance specification, and a firm of marine advisers, Y-Ard Ltd, was engaged to enlarge this to a detailed specification. Tenders were then invited for the detailed design and construction of the vessel. Consideration was

Downloaded from http://ftp.nowpublishers.com/jpric/article-pdf/60/4/699/2570518/iicep_1976_3375.pdf by guest c

given in the early stages to the incorporation of a dock facility in the bund wall which was to form the seaward boundary of the sewage treatment works site. This would certainly have allowed a considerable saving in operating costs by avoiding harbour dues, but the depth of water in the area concerned was unfortunately much too shallow to accommodate a vessel with the draft of 4·5 m or so which was required.

127. The placing of the effluent outfall with respect to the area within which mineral abstraction has taken place has been queried. In fact the Midlothian coalfield is bounded on the west by the Pentland Fault and this is some 4 km to the east of the line of the effluent outfall.

128. **Mr Banks** questioned the extent of the ecological survey. The purpose of this survey is to attempt to assess the improvement in quality of the estuary waters in the intertidal zone brought about by the scheme. The opinion has already been given that there are ecological conditions at the moment resulting from pollution by the existing discharges of crude sewage from the existing short outfalls and these conditions will change with operation of the scheme. It is therefore the change resulting from implementation of the scheme which has to be monitored: after that is complete it is not anticipated that there will be any detectable evidence of pollution along the coastline. The northern coastline of the estuary is so much further distant from the existing and future discharge points that no evidence of pollution from Edinburgh will be detectable either now or in the future. In addition there are a number of crude sewage discharges through short outfalls on the northern side and any conceivable effect from Edinburgh would be infinitesimal by comparison.

129. The original tentative area for disposal of the sludge was a short distance to the east of the Isle of May at the mouth of the estuary. It emerged only at a later stage in the general investigations that there were important fishing areas nearby for the creature *Nephrops* or Norway lobster—the scampi of the catering trade. The Department of Agriculture and Fisheries for Scotland then carried out investigations into a number of likely areas and consulted the fishermen operating off east central Scotland. Eventually an area was found which the Department considered acceptable from the aspect of overall protection of fisheries and to which the fishermen raised no objection. This is the area now established for the disposal operation. The time for a normal trip to and from the discharge area is expected to be some 10 h. As already indicated, with the completion of the full Edinburgh scheme and the arrangement for transfer by road tanker of sludge from other works within the Lothian region, five sailings per week are expected. The crew will be composed of the captain, three other officers and six seamen and motormen. A service for the overall sludge disposal operation by a commercial firm was considered in the early stages but rejected on the grounds of cost. Details of the storage capacity normally available for the sludge have been given. In addition, the storm tanks could be used in an emergency to provide further storage.

130. The size of the storm tanks has also been given. These tanks are primarily for use as holding tanks to reduce the peak flows in the effluent outfall during times of storm to a value that could be accepted by the outfall without causing 'backing-up' within the works during the upper part of the tidal cycle. The size of the outfall could not be increased as minimum velocity requirements during low flow could not then be met. The raising of the level of the treatment works would have overcome the problem but the resulting rise in level of the interceptor sewer system would have required a new alignment further inland and a basic aim with the scheme has been to reduce to a minimum the extent of the coastal strip for which sewage pumping is required.

131. **Mr Buchanan** referred to the points made by other questioners on the subject of the length of the effluent outfall. Quite simply, the length of 2·8 km actually constructed is that planned from the beginning as being necessary, along with the diffuser system, to give acceptable conditions in the area of estuary concerned. A short section of construction in the further reaches was unexpectedly found to be in clay. The method of construction over this section was then changed from colliery arch support to conventional concrete segments. Since this occurred almost at the end of the tunnel and the

Downloaded from http://ftp.nowpublishers.com/jpric/article-pdf/60/4/699/2570518/iicep_1976_3375.pdf by guest

construction presented no difficulties, a departure from the original intentions, say by sloping upwards to a seabed pipeline, did not arise.

132. On the question of an improvement of the environment around Cramond and elsewhere along the coastline, we would have thought that to be a principal objective of the scheme. The occupation of a length of frontage to the estuary by the sewage treatment works has produced no complaints. It is immediately adjacent to an industrial area and, before our reclamation operations began, sewage solids stranded in that area used to give rise periodically to serious smell nuisance.

133. A reduction in the surface and ground water taken into the existing combined sewers is taking place slowly but significantly as areas of the city are undergoing redevelopment and new development is going ahead. Also a number of surface water sewers are being constructed each year and the opportunity is taken to connect to them surface water discharges which are at present connected to the combined sewers.

134. Replying to **Mr Austin**'s enquiry for information on the siphons incorporated in the interceptor sewers, the first is included to carry the western interceptor sewer beneath the bed of the Water of Leith river. It is formed of three pipes, two of which are 1067 mm in diameter and the third is 1829 mm in diameter. Each pipe includes an almost level central section preceded and followed by inclined legs, and each of the pipes can be isolated by penstocks at both ends. A valve chamber straddles the three pipes at a position near the foot of one of the inclined legs and the valves will allow any pipe to be emptied by means of pumping, and cleaning will be carried out using a pull-through arrangement.

135. The large siphon to carry the combined flow from the interceptor sewers into the treatment works site is formed of three pipes 2100 mm in diameter. Again each pipe includes a central section laid at shallow gradient with inclined legs at either end and each pipe can be closed by means of a penstock installed within a penstock house at the inlet and a further penstock in the feed channel within the treatment works site. The lowest points fall within the works site and drain-off pipes fitted with sluice valves have been incorporated at these points and connected to the site low-level drainage system. As the rate of main flow to the works allows a pipe to be taken out of operation, it will be isolated and drained. The size of the pipes will allow manual inspection and clearing of any heavy debris which accumulates.

136. **Mr Lonsdell** raised the question of ventilation of the interceptor sewer system. The main ventilation point for the release of air displaced by sudden heavy flows is the penstock house at the entrance to the siphon carrying the main flow to the treatment works site. This house is in an elevated position in a disused railway embankment and some distance from inhabited property.

137. The possibility of 'playing tunes' with the interceptor system by varying the rates of flow accepted into the system is particularly interesting. The intensity of rainfall will undoubtedly vary over the city area during most storm events and the aim should be to utilize the full capacity of the interceptors so far as possible. For practical reasons, additional control over the inputs has been confined to three points. Two of the points are shown in Fig. 3 at drainage 900 m on the eastern interceptor sewer and at 2900 m on the western interceptor sewer where sensors are to be installed and linked in with the control and instrumentation system at the sewage works. Penstocks at these interception points will be operated remotely from the works to allow rates of flow well beyond the calculated maxima to enter the interceptor sewers to take up any spare capacity available if the inputs upstream have not reached their full allowance. The third point for additional control is a large pumping station in the coastal strip which will feed directly to the sewage treatment works and the rate of feed will similarly be increased beyond the calculated maximum if spare capacity is available.

138. The adoption of a conventional storm tank layout would have required a greater number of smaller tanks than the four large ones which have been constructed, along with the sludge scraper machinery at high capital cost and involving substantial maintenance costs all for use only occasionally. The use of a tractor-mounted squeegee will

Downloaded from http://ftp.nowpublishers.com/jpric/article-pdf/60/4/699/2570518/iicep_1976_3375.pdf by guest

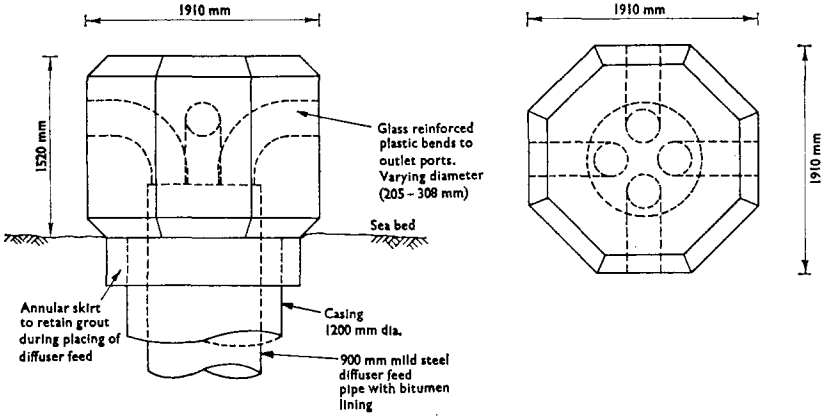

Fig. 21. Details of diffuser head

give an unsophisticated but, we believe, an effective sludge removal arrangement.

139. The diffuser system on the effluent outfall consists of nineteen heads with four diffuser ports and a further one, the outermost, with six ports. The details of a diffuser head are given in Fig. 21. Damage of the heads by anchoring of shipping must always be a possibility but we think the risk is very slight. The area concerned is not one where shipping approaching Leith Docks tends to anchor and buoys have been placed at either end of the diffuser section to warn against lying at anchor in this area. The shape of the diffuser heads is also aimed at reducing the risk of an anchor lodging against them.

References

1. COATES T. The Belle Greve outfall tunnel. *Tnls Tnlng*, 1969–70, **1–2**, July, 209–214; Belle Greve outfall tunnel, sea bed breakout. *Tnls Tnlng*, 1971, **3**, July, 282–3.
2. STAYNES T. M. Discussion on papers 1 and 2. *Annual Conference*, Institute of Water Pollution Control, 1975, in press.
3. APPLETON B. Coming apart at the seals. *New Civ. Engr.* 1973, 6 Dec., 6–9.

Downloaded from http://ftp.nowpublishers.com/jpric/article-pdf/60/4/699/2570518/iicep_1976_3375.pdf by guest