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The Ulu Pandan sewage disposal scheme, Singapore†

by

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and

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Discussion

Mr A. F. Daldy (Civil Engineer, D.S.I.R. Building Research Station) said that about 15 months ago he had been fortunate enough to visit Singapore. He was interested in the gravity sewer which was then crossing a swampy and peaty valley. As had been seen from the slides, there was a 72-in. pipe surrounded by concrete, the whole supported by a grid of bakau wood piles about 15 ft long and 4-in. dia. set at 15-in. centres along and across the trench. Except in the middle of the valley the piles penetrated through the peat to better ground below. A section of it would be as indicated in Fig. 10 below:

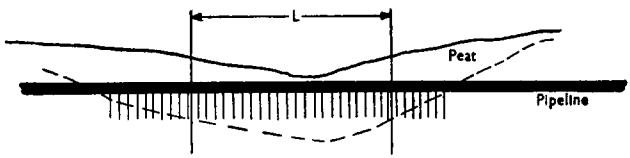

FIG. 10.—SECTIONAL VIEW OF PILES

136. Where the piles ceased to go into the ground (length L) and went only as far as the peat, was there any subsequent differential settlement for the flexible joint to take up? He asked that question because he had another question to ask about the flexible joint in that particular pipe. He was not clear whether the pile-cap of concrete was continuous under the flexible joints or whether it was broken at them.

137. As he read § 132 there were flexible joints at every pipe but only at every second or third joint in the surround. He was not quite clear why there were flexible joints if they were to be surrounded with concrete afterwards. The pipeline was a reinforced concrete one and also had concrete round it; he assumed that this was to add weight to the pipe line and stop it floating when it was empty.

138. He had not met in this country the Tylox A rubber joints for ogee pipes and would be very grateful for some information as to where he could find out a little more about them.

139. Referring again to the flexible joints, was there any appreciable movement at the points he had mentioned, because they seemed to be potential fracture planes; he would be very interested to know whether the flexible arrangements worked adequately as they stood.

† Proc. Instn civ. Engrs, vol. 21, (Jan. 1962), pp. 13–36.

Mr G. M. Richards (Chief Assistant Engineer, Main Drainage Capital Works, Bristol Corporation) said that from 1956 to 1959 he held the position of Chief Sewage Engineer for the City of Singapore, and before that for three years he had been Assistant Engineer also for the City of Singapore. The very fine scheme which had been so ably described by the Authors tonight was commenced during the period of his office with the City Council of Singapore, and for that reason it was of particular interest to him.

141. Modern sewage treatment works, however, embraced such a wide diversity of design and operation that he would concentrate on what might appear to be one very small aspect of such a big scheme. That aspect was the design of the aerated spiral-flow detritus channels. Although these had been used in America and Germany he believed that the first one was constructed in England in approximately 1957, and a year later a set of channels was constructed for the Kim Chuan Road Sewage Works extensions, also in Singapore, based on a similar principle. Since then a large number of spiral-flow channels had been constructed both in the United Kingdom and overseas, and in general it could be said that the spiral-flow aerated channel today tended to replace the conventional constant-velocity channel. But whereas the design of the constant-velocity channel was based on accepted hydraulic principles there appeared to be very little scientific information available to guide the engineer in the design of the spiral-flow channel.

142. Two years previously, in considering the design of the new sewage treatment works in Bristol, they had tried to make a mathematical analysis of the behaviour of the grit particles in a rotating mass of liquid. The results suggested that the spiral-flow channel might be not a highly efficient method of removing detritus from sewage. For the purpose of the analysis certain assumptions had to be made. One of these was that the detritus entered the channel evenly distributed throughout the body of the sewage. The second assumption was that the general motion of the sewage in the detritus channel was a forced vortex. Neither of these assumptions was true, therefore some results might be arrived at which were equally untrue. Nevertheless, he would proceed to explain the results of a purely mathematical analysis of the behaviour of grit in a rotating mass of fluid. The conclusion had been reached that for the normal range of angular velocities with which one was dealing in the spiral-flow channel, the centrifugal effect on the grit particles was very small and could be neglected. In short, the spiral flow channel did not behave as a centrifuge; it did not centrifuge the particles outward but got rid of them in some other way. Proceeding with the analysis of the behaviour of particles they had come to the conclusion that, viewed from the end of the channel, end on, the orbit of all solid particles was circular. The fluid was rotating in a circular manner and the grit particles suspended in that fluid, i.e. in the sewage, were also moving in a circular orbit. But the centre of rotation of the grit particles was displaced horizontally from the centre of rotation of the fluid, and the displacement could be calculated mathematically. It was actually equal to $\frac{V_0}{\omega}$ where V_0 was the settling velocity of the particles in quiescent conditions and ω was the angular velocity of rotation.

143. That very simple fact was quite an important break-through, because it led immediately to a whole field of analysis where further results were obtained. One of the interesting results was that if one ignored the centrifugal effect of the rotation on the sand particles, all the sand removed would be removed in the first complete rotation of the fluid. The conclusion was also reached that in order to move 100% of any particular size particle, the peripheral velocity of rotation should be not greater than the settling velocity of that particular particle. Another surprising conclusion reached was that the surface area of the spiral flow channels required for 100% removal of any particular particle was given by the equation that the surface area was equal to $\frac{4.Q}{V_0}$ where Q was the quantity per second. This compared rather unfavourably with normal sedimentation, where it was accepted that the surface area required was equal to the quantity over the velocity and not four times the quantity over the velocity.

All this was purely mathematical and might bear very little relationship to the actual behaviour of the particles in the rotating liquid.

144. Was the design of the spiral-flow channels in the scheme actually based on such mathematical analysis or on rule of thumb? Had the Authors any evidence from the operation of similar channels which would indicate a general efficiency in excess of that suggested by purely mathematical analysis?

145. It appeared to him that some advantage would necessarily accrue from the physical separation of the grit from the large organic materials by the violent agitation consequent upon the aeration. He felt that this might be preferably achieved by combining aeration with vertical settlement rather than with the spiral settlement adopted in these grit channels.

Mr A. T. Sneller (Senior Engineer, J. D. and D. M. Watson) proposed to limit himself to certain factors affecting the design of the works and to deal with two specific aspects of the works, one of which happened to be the spiral flow grit channels, to which Mr Richards had just referred.

147. First of all, it was true to say that the design of the scheme as a whole had followed generally accepted practice in the United Kingdom for sewage purification works and sewerage systems but it had been somewhat modified by the conditions in Singapore. He put those under three main heads, climate, labour, and the available materials.

148. Dealing with climate first of all, the high temperature, 84°F, of the sewage and the consequent rapidity with which it became septic necessitated careful consideration of all retention times and also velocities of flow in the sewers. Added to that one had to remember that the Singapore sewers had been laid at what would be considered very flat gradients, giving velocities of 2 ft/sec. and sometimes less, so that the sewage arriving at Tanglin Road pumping station was probably between one and two hours old. By the time it had got to the works, which took in the very best circumstances another hour and a half, the sewage was far from fresh, and unless care was taken it became very septic and consequently more difficult to treat. The retention times in the sedimentation tanks had been kept down to the minimum, as had been thought at that time, but (as Mr Cripps had already intimated) it was now thought that this should be reduced still further in the light of the conditions already found at Ulu Pandan.

149. Not only did the sewage become septic but in becoming septic, of course, gases were evolved and it was necessary to ventilate both the sewers and the wells of the sewage- and sludge-pumping stations. Forced ventilation had been provided in the sewage and sludge wells, and although that had gone a long way he now felt they should have been more bold in their installation of ventilating equipment.

150. Another point that had to be considered in Singapore was the presence of mosquitoes, so that such things as catch pits, stilling bays, and any other arrangements where water was likely to stand had to be avoided. That is, all surfaces must be drainable at all times, and gulley pots such as used in British road drainage were not permissible.

151. The high humidity in the atmosphere made it necessary for the steelwork to be carefully protected against corrosion, and aluminium metal spraying had been extensively used; all the sludge scraping equipment, metering and electrical cabinets had been aluminium metal-sprayed, followed by zinc-chromate painting. "Weatherproof" electrical and metering equipment was found to need some added protection against driving rain and the intense sunshine.

152. All buildings were orientated on an east-west axis. When the architects propounded this idea it was a bit inconvenient to the engineering layout and the engineers had opposed it, but the architects had been quite right and the buildings were cool and well shaded. Singapore being just off the equator, the sun was never at midday at a greater angle to the vertical than 23°, so by overhanging the aluminium roof over

the windows, to a limited extent, they were normally kept in the shade, and as a result, the buildings were very pleasant, cool, light, and airy.

153. The operatives about the works also required a certain amount of shade from the sun and protection from the rain. The aeration tank control walkway, that had been referred to by Mr Oakley had an aluminium covering, fixed to mild steel supports, and this had been very successful. The wind being generally at right angles to it (and also to the buildings), kept these locations pleasantly cool. All the instruments, pumps and switchgear associated with the diffused air plant were protected by this covering. This had not been done in other situations and he was persuaded that somewhat wider covering could have been done, in particular between the sedimentation tanks.

154. Skilled labour was not very readily available in Singapore, and in designing works consideration had been given to avoiding any intricate automatic devices but aiming for equipment that was robust and well designed, requiring a minimum of maintenance. The men were generally small and tended to be disinterested in work, so that every operation and access thereto had to be made as easy as possible. Penstocks and sluice valves had been specified as requiring an operating effort against the maximum unbalanced head of less than 50 lb. Colour coding had been extensively employed, e.g. on all penstocks and pipelines, so as to make operation as simple as possible. There were other aspects that could be mentioned but those were the main ones so far as labour was concerned.

155. All the concrete had been made from crushed granite. Gravel was not available in Singapore and proper concreting sand was very hard to come by. In the earlier contracts the cement was limited to British cement but latterly the Council had viewed that with less favour because of the cheapness of Japanese cement, and that had been used, but it had been found necessary to weigh every bag because a variation of 1 to 2% had been found on the 50-kg bags. Steel had been European throughout and in general had been reasonably available, but shipping strikes and the Suez crisis had made certain difficulties. At the design stage it was assumed that there would not be any difficulty in getting good quality concrete, and, as had been seen, this had been achieved. Engineering bricks were not available and other materials had had to be used. In the inverts of manholes concrete linings had apparently been used with success. Aluminium was readily available and, as had been seen, the roof covering to the Power House and Tanglin Road pumping station had been sheeted with aluminium which also helped to reflect the sun's rays. Aluminium trusses had also been used for lightness and maintenance costs.

156. Prestressed concrete had been available, in particular 2-in.-thick prestressed concrete planks on prestressed concrete beams had been used in the aeration tank control walkway and also on the walkways out to the secondary sludge digestion tanks. They had been economic and very satisfactory.

157. Turning to the spiral-flow grit channels, one disadvantage of the conventional parabolic grit channel was its lack of capacity to store grit, particularly in times of high flow, the grit tending to be carried through into the works. Another difficulty was to control the forward velocity so that one could be reasonably certain that the organic material would not be settled out in the channel but that all the grit would be deposited. As Mr Richards said, the flow was certainly not a forced vortex in its entirety, and he could assure him that these grit channels were not designed on any intensely theoretical mathematical basis. It was known that they worked in America, and there were some operating in Britain. A certain amount of time had been devoted to basic design but without going into the detailed calculations in which Mr Richards appeared to have become involved. The grit did tend to settle out rather heavily at the inlet end but he was fairly certain from his own observations that the grit settled out in the whole length but in decreasing concentration. They were for that reason considering shortening equivalent channels for the new scheme.

158. The second point of design was the crossing of a number of streams into the drainage canal by the main gravity sewer, laid alongside it, from the discharge chamber

down to the Works. Some of these crossings were at such a level that they could be taken underneath the sewer, and that had been done whenever possible. At other times the levels were such that they had had to be taken over the top, and in order to avoid erosion of the canal bank the flow was cascaded down into the drainage canal by the structure shown. This enabled very small flows to be taken quite satisfactorily down into the canal, and high flows could cascade down, destroying the energy in the water and so preventing any erosion.

159. In conclusion he wished to say how much he had enjoyed working with the Authors during the last 6½ years in carrying out this scheme from its inception to its completion.

Mr G. B. Lewis (Consulting Engineer) said that he wished to consider Fig. 5b, the arrangement of the Tanglin Road pumping station. The building was large, 120 ft by 30 ft by 50 ft, required solely for the protection of nine comparatively small pump motors and a small switch-board. There was no doubt that the correct way of handling large quantities of sewage was by the dry sump type of pump which had been employed in this station, the motors and the switchgear being above flood level, but he was wondering whether his education was not now out of date. Had the Authors considered mounting the motors immediately on top of the pumps, leaving only sufficient space between the motor-shaft extension and the pump coupling to enable the pump shaft and impeller to be removed for maintenance or replacement, very little else being required in the working life of pumps of this order? Having placed the motors in the basement, how often would they be flooded? Flooding could occur either as a result of a pump gland failing or by a pump attendant taking one of the covers off when he had not completed isolating the pump by valving. In his experience that did not often happen, and in the case of Tanglin Road and possibly at the pumping station at Ulu Pandan, it seemed to him that if the sump were divided into, say, three parts with three pumps in each one, considerable cost could be saved, and that with a minimum of risk, leaving the building a comparatively small one, required for the protection only of the switchgear and of such additional ventilation plant as might be needed for the ventilation of the dry sump.

161. Assuming the worst came to the worst and one or two of the sumps were flooded during the working lifetime, the washing down and drying out of a pump motor was not very difficult.

162. Would the Authors state what considerations led to the selection of the power-house as the place for the main air compressing sets? They were large, expensive pieces of machinery and there was space for four of them, of which three might be needed at any one time. In addition, between the power house and the aeration channels there was a difficult and expensive air main. Had the Authors considered the use of a multiplicity of small positive displacement air compressors distributed along the length of the aeration tank, possibly on the walkway, where they could be maintained quite readily, and if necessary removed completely and replaced by spare gear?

163. Was an electricity service to Tanglin Road pumping station from the Ulu Pandan generating plant not considered? All main lift sewage pumping stations represent a poor load for any electricity supply authority, and their dislike of the load is reflected in the amount of the capital contribution asked for, and the tariff. One had to pay for the fact that the electricity authority did not like the load: it entailed keeping generating capacity available for supplying the whole of the pumping station plant at all times.

164. Having set up the Power House watch-keeping organization at the Ulu Pandan works, it seemed to him that a comparatively minor additional expense for cable, between 4½ miles of 3·3 kV or possibly 11 kV cable, laid at the same time as the pumping mains (there would have been two cables for continuity purposes), together with a control and indicator circuit cable, would have enabled the pumping station load to

be taken by the Ulu Pandan generating station and placed under the control and supervision of the staff there.

165. At Tanglin Road there was an emergency spillway to the adjacent canal so that at times of power failures (which were bound to occur in the best of electricity supplies) the emergency penstocks might close and the flow be diverted to the canal. It seemed to him that that was something which could be used with advantage very much more in the United Kingdom, where at the moment, generally owing to the nature of the agreement between the sewage disposal authority and the river authority, the former was obliged to receive and treat all flows in the sewer. In cases of electricity supply failure, over which there was little or no control, the sewage disposal authority had to make provision for handling the sewage, involving considerable expense in insurance plant. Such plant was seldom used, and, when it was, did not always work properly. What were the Authors' views on the point?

166. It would be noted that the temperature of the sewage coming forward to the works in Singapore was roughly 20°F higher than was customary in the U.K., so that the amount of heat required for digestion was comparatively low, and he would have expected the engines to be designed for maximum efficiency to work, rather than (as was more customary in this country) a balance between energy to heat and energy to work. Even so, he would have expected there to be ample heat energy available and at the correct grade for mesophilic digestion. Were the Authors satisfied that, using exhaust heat for topping up the grade of the jacket water, they would have sufficient heat available at about 180°F for thermophilic digestion, and, if not, had they considered the use of immersion heaters to top up the grade of heat for that purpose?

Mr H. R. Lupton (Consulting Engineer) first drew attention to the use of three separate pumping mains from the Tanglin Road pumping station. Thus a scouring velocity could be ensured in the rising main, at small flows, by using only one of the mains. Also the age of the sewage arriving at the Treatment Station could be kept to a minimum. Not only sewage flows might be concerned—he was at present doing the same thing with a raw-water supply from a river liable to contain large amounts of silt. Initially one pipe only was being installed, which was much smaller than the main (of optimum economic diameter) through which the same water, filtered, was afterwards pumped. As the scheme expanded one, or two, more pipes would be put in in parallel with the present one, so that it would always be possible to carry the flow at a speed great enough to prevent siltation.

168. He noticed, with considerable admiration, that apparently the pumps at Ulu Pandan had no non-return valves. Each unit, it appeared from the drawing, delivered into the delivery flame without the noise and the occasional hammer of a non-return flap—always a device to be avoided if possible.

169. Of great interest, he thought, was the use of a positive sludge pump, a ram-pump, for various purposes, but in particular for clearing blockages in the sludge pipes anywhere in the system. But if one put in a positive pump, which cost more than a centrifugal pump and, presumably, was considerably more efficient, why not use *it* for continuous running and the centrifugal pumps, with their lower efficiency pumping sludge, as the standbys? Was it perhaps, that the upkeep of the positive ram-pump might cost more than the upkeep of the centrifugal pumps? He was also interested to know what kind of valves, and what kind of packing, were used in these sludge-pumps.

170. A point in which he had considerable personal interest was the surge-prevention device at Tanglin Road. After a very complete investigation by the Firm, and particularly by Mr Norton, who examined a variety of methods which could be used to prevent objectionable surge, the provision of increased inertia, by means of fly-wheels on the driving motors, was selected. It was not always realized that where this method could be adopted (it could not generally be adopted economically when the power was considerable because the size of the flywheels became excessive) it had the advantage of preventing not only water hammer in the rising-main but also the hammer of the shutting

non-return valves—in other words, it protected against shock the non-return valves themselves as well as the rising-main. It had this advantage, for instance, as compared with the use of an air-cushion which, while providing the energy to keep the flow along the main from diminishing too quickly, did not prevent the non-return valve from shutting quickly—making it shut, in fact, more quickly than if there had been no air-vessel. It was now possible to ascertain the speed with which the flap of a non-return valve, in a circuit, would shut. In the present case the fly-wheels had been designed to ensure that the rate of shutting should at any rate be much less than that at which the flap would fall shut in air. Could the Authors say whether the valves closed quickly or not?

171. Mr. Sneller had mentioned the gasification of the sewage. Recent investigations of the surge-valve velocity in sewage fluids had shown most anomalous results. In one case the surge velocity was less than half of what it would be in ordinary water, owing, he supposed to the elasticity of the inclusions of gas in the sewage. This made the liquid much "softer"—i.e. it greatly reduced the bulk-modulus.

172. Sludge metering, sewage metering and other measurements were mentioned. It would be interesting to know what nature of instrument was used for the metering of the sludge flow. He wondered whether the magnetic meter had been applied at all at Singapore. It did seem to have advantages where liquids had to be measured carrying solids which might obstruct an orifice or other constructive device, but which could hardly obstruct the uniform through-passage of a magnetic meter.

173. He was also interested in the comminutors at Tanglin Road. Through these passed the whole sewage flow, so they had to be of a moderate size. In the final scheme only 70% of the total flow coming to the treatment station would come via Tanglin Road, so that 30% of the incoming sewage would retain its solids uncomminuted. Was it only to save the pumps from being obstructed that the comminutors had been installed? If, on the other hand, the object was to cut up the objects in the sludge so that they might adjust more rapidly, then would it not be better to comminute only the sludge, not the whole flow of the sewage (thus using a smaller machine) and to do it at the treatment works, not at Tanglin Road.

Mr E. H. Ely (Senior Assistant, J. D. & D. M. Watson) referred to the cross-section of the power house and pumping station on page 33 of the Paper. Bearing in mind the poor ground, what precautions were taken in the design and during construction to avoid movement between the main part of the building and that containing the deep sump?

Mr R. P. Whiting (Senior Engineer, Scott & Wilson, Kirkpatrick & Partners) referred to Fig. 3 on page 16, the graph of the dry weather flow per head. The curious note appeared, "Estimated figures from 1955 (meters out of action)". What meters were they and why were they out of action for three years, and, since they were out of action, why was it assumed that the dry weather flow dropped from 40 to about 32, and why, nevertheless, did the Authors select a design figure of 60? Then, from Table I on page 17, in the first stage the dry weather flow was assumed to be 60 and in the final stage it was assumed to be the same; the assumption appeared to be that the dry weather flow per head would go on rising until about 1963 and would then level off. Could the Authors comment on this? The designers seemed to have been unfortunate in having had to have the sewage pumped twice over; it was first pumped at Tanglin Road, and then again at the sewage works against a head of as much as 40 ft. He would have thought that as pumping at Tanglin Road was required anyhow, the works could have been sited rather higher up so that pumping was to a greater head at Tanglin Road, but the flow through the works was entirely by gravity. Perhaps the reason lay in the configuration of the site but he would like to have that confirmed.

176. Finally, he noticed from the plan on page 15 that the effluent outfall ran for some distance to a creek, and the Authors had referred to possible pollution of it. It

would appear, however, that there was a shorter route straight out to sea to the south; could not that have been adopted?

Mr E. L. Barron (Senior Engineer, Brandt & O'Dell) said that in § 52 the Authors stated that the water level was lowered by subsoil drains, and that the remaining upthrust was met by the weight of the structure and superload. The subsoil drains were shown below the structure, but apparently were not considered adequate to drain the ground-water to this level, since otherwise there would have been no remaining upthrust. What lowering of the water table had the Authors considered could be obtained by the subsoil drains, and were observation tubes provided for checking their effectiveness? Did the inclusion of superload in the weight required to meet the upthrust result in operational limitations? The siting of the drain under the structure, as shown in Fig. 5c, permitted less excavation but gave rise to the danger of crushing the pipes unless non-rigid pipes were used. Fig. 5a showed dotted circles on the external corners of the subsoil drain. Were these manholes or cleanouts? What was the tapered device leading from the surface water interceptor drain to ground level in Fig. 5b?

178. In the powerhouse the problem was to dispose of the heat generated internally while excluding solar heat. This could be achieved simply by a non-insulated roof with the exterior painted white. Fig. 8b showed a more elaborate arrangement comprising ceiling and double skin roof. Was the ceiling space ventilated by fans and could the Authors give temperatures of the ceiling and roof surfaces for the severest exterior and interior conditions? Was an upstand provided to the flat edge of the roof to form a gutter or was the water allowed to fall on to the flat roofs below? Could the Authors indicate how the ventilation air was distributed in the engine room and basement? Did the engine manufacturers experience difficulty with the different lengths of exhaust pipe, or with overheating of the silencers when heat was not required for the sludge? Did the Authors consider electrically operated cranes to be justifiable for 5- and 10-ton cranes used for maintenance? Were the reinforced concrete crane beams considered to be more economic than steel for the 10-ton crane?

179. In the October 1951 Journal of the Institution[2] it was stated that some pollution of streams and open drains provided a very suitable method of preventing the breeding of mosquitoes. Did the Authors subscribe to this view?

The Chairman, Mr J. A. Banks (Partner, Babtie Shaw & Morton) commented that the engineers' work on the design of the project was simplified by the area being drained on a separate system, and the fact that rainfalls of 4 in./hour were not uncommon was perhaps irrelevant. How dirty was the storm-water and how was it disposed of? In a strictly separate system little or no grit was to be expected and what was the source of the grit for the removal of which quite elaborate measures had to be taken?

181. On the matter of septicity of the sewage, referred to particularly by Mr Sneller, he wondered whether in-sewer chlorination was considered a means to prevent or delay the onset of septicity in the pumping mains.

182. It was not an agreeable thought that the outfall had to be situated where shellfish and prawns were cultivated. One was led to be very suspicious of shellfish which were to be found in somewhat polluted estuaries. There was a reference in the Paper (§ 16) that rather left the impression that the river was already polluted and that the quantity of effluent was small in relation to fresh-water flow. The passage stated: "It was therefore agreed that the discharge of effluent fully treated to a 20:30 standard was permissible, and that tertiary treatment would not be justified." Surely the fact that the river was polluted had little influence on the standard of effluent that was required, particularly when shellfish were known to be present?

The following contribution was received in writing:

Mr J. K. Tattersall (H. G. Acres & Company Limited, Consulting Engineers, Niagara

Falls) observed that the air quantities provided for the spiral flow grit channels at the Tanglin Road Pumping Station appeared to be about 1-1/2 cu.ft/min./lineal ft. Has any difficulty arisen in moving grit? The tendency in North America was to provide about twice this amount of air, and in view of the fact that air had been supplied to delay septicity during the long travel periods had the amount of air provided proved adequate in practice?

184. What type of meters were used for metering the raw sludge to the digesters, and was sludge pumping controlled manually or on an automatically timed or density control?

185. The vertical return sludge pumps were mentioned as having variable speed control. Was this done electrically or mechanically?

186. Discussions over the pros and cons of installing circular primary sedimentation tanks as against rectangular tanks never seemed to be finally resolved. In Canada the severity of the winter militated against the use of "Meider" type scrapers, leaving only the chain flight type of scraper for rectangular tanks. The argument then developed along the lines of weighing the structural advantages of common wall construction against increased maintenance for chains, and possibly reduced efficiency. Would the Authors care to say what led them to choose circular tanks?

187. The treatment of sludge was always one of the most expensive portions of a sewage disposal scheme, and it had been interesting to see that thermophilic digestion might be used at this plant. In colder climates it was expensive enough just to maintain mesophilic conditions and that, coupled with a reputation for sensitivity and poor supernatant from the thermophilic digestion, had meant that the latter was never considered in Canada so far as Mr Tattersall knew. Was any special provision made for supernatant selection from the secondary digesters, and how was the supernatant returned to the plant, or dealt with separately?

The Authors, in reply, said that they were pleased to have the opportunity of remedying an omission in the Paper by recording the great interest that had been shown in this scheme by the Municipality, and latterly the Government of Singapore and by successive City Engineers, especially the present holder of that office, Dr Ng Wah Hing, Ph.D., M.I.C.E., and of formally thanking them for permission to publish the Paper.

189. With regard to Mr Daldy's observations, bakau piles were regarded as being essentially friction piles. Insofar as they penetrated to relatively good ground at the valley sides, so providing a measure of end bearing, or in any transitional length from raft foundation on good ground to bakau piling in peat, differential settlement was to be expected, but the flexibility of the pipeline was considered to provide an adequate safeguard.

190. The pipe joints were of the rubber ring type to provide positive jointing as well as flexibility. Flexibility in the surround was introduced by the prevention of bond between the successive lengths of the surround for each day's work, which varied between two and three pipe lengths. The surround was primarily to provide additional strength in the pipeline.

191. The Tylox joint is not yet well known in this country, but one of the leading concrete pipe manufacturers can now provide information about it for both ogee and socketted pipes.

192. The arrangements for pipeline flexibility appeared to be working adequately.

193. The spiral flow grit channels had evoked some interest and the Authors appreciated the comments made by Mr Richards. The channels at Tanglin Road were based on a study of successful designs in the U.S.A., notably that at Columbus, Ohio[5], and followed closely on the lines of those installed at Derby, England[6]. The theory on which the design was based was that the cross-flow on the floor of the channel could be adjusted to 1 ft/sec. (or any other chosen value) by control of the air supply, and was largely independent of the forward velocity—hence the shape of the channel, which was unlike those described by Pöpel[7]. The Authors, like Mr Richards, had been attracted

to a design based on controlled turbulence in the channels, but the spiral flow design had the advantage of sweeping the grit to one side where it was easily collected.

194. The Authors thanked Mr Sneller for the interesting additional information he had given about the scheme.

195. The Authors thought that the building appropriate to Mr Lewis's lines of thought might not be significantly cheaper than in their scheme, assuming that it would be necessary to provide a crane. They considered that it was preferable to accept the additional cost of their building, housing the motors at a high level, than to run the risk, however remote, of the inundation of a large section of the plant. Incidentally, the sub-structure Mr Lewis had in mind might be appreciably more costly than that in the Authors' scheme on account of the additional transverse walls in the substructure and additional stairways, and might be considerably less convenient as regards maintenance.

196. The Authors also did not think that it would be cheaper to use a multiplicity of small local compressors for the aeration plant and were of the opinion that it was sound design to concentrate the important machinery in a few large units under one roof, rather than disperse it in smaller units over the works, and this was particularly true of Singapore, where skilled labour was now difficult to find.

197. Mr Lewis had suggested supplying power to Tanglin Road pumping station from Ulu Pandan. The objections to this were partly economic—depending on the estimated yield of sludge gas—and partly the vulnerability of the power and control cable in the undeveloped country through which the gravity sewer runs.

198. The Authors agreed that the question of emergency spillway for use in times of power failure should receive consideration in United Kingdom schemes. The extent to which it was permissible to accept an overflow or to which it was desirable or essential to provide insurance plant depended on the circumstances of each case, and the possible scale and significance of the pollution that might be involved.

199. Following the usual practice, the engines were designed for maximum efficiency to work, but ample heat was available for thermophilic digestion and no provision has been made for the inclusion of immersion heaters.

200. Mr Lupton queried whether the ram pump might not have been used as the main duty pump. Its efficiency is better than that of the centrifugal pumps, but it was considerably more expensive in capital and maintenance costs. The valves are of the reinforced rubber flap type, loosely hinged, and the spindle packing is by stuffing-box and gland. The main reflux valves in the Tanglin Road station close slowly and without noise.

201. Several questions had been asked on the handling and control of sludge. Sludge withdrawal was by visual and manual control, but the sludge pumps were automatically controlled by electrodes in the sludge sump. Two magnetic flux meters were installed for the measurement of raw and digested sludge, but metering of other sludge flows was by simpler and less expensive types of differential-head meters. Comminutors help to avoid operational difficulties but their primary function was to protect the pumps, and any of the 30% balance of the flow that might be pumped from elsewhere would be similarly treated.

202. The reply to Mr Ely's question on movement of the power house was that this was founded in good firm material.

203. The Chairman, Mr Barron, and Mr Whiting had all asked questions on the sewerage system which were strictly outside the scope of the Paper, or, indeed, the Authors' responsibility. The reference to the meters was extracted from the City Engineer's Report, and relates to meters on the rising mains from subsidiary pumping stations. Reference to Fig. 3 would show that when the basic design was formulated the apparent drop in flow per head was not known, and could not have been foreseen; however, apart from the trouble with the meters, there was some doubt as to whether the drop was real, since the assessment of population served was a matter of some difficulty.

204. Mr Whiting had misinterpreted the "trend" line shown on Fig. 3; this could not of course be extrapolated, and one would expect the rate of increase to fall as the flow increased. The only assumption made was that 60 gal./head/day was the ultimate rate that would be expected during the useful life of the works, and in arriving at this conclusion due regard was paid to such other factors as water supply forecasts, future standards of living, and experience in comparable situations. As to Mr Whiting's second point, the reasons for the choice of pumping twice were given in § 60 of the Paper.

205. In answer to Mr Whiting's comment on the effluent outfall, the terrain was such that the line chosen was the shortest practicable route to a suitable point for discharge.

206. In reply to Mr Barron, the rubble drains below the structure were used only during construction. The groundwater was effectively lowered to the level of the upper drain shown on Fig. 5c and the dotted circles shown on Figs 5a and 5c are manholes on this drain. No operational limitations resulted from the inclusion of the earth superload.

207. The Authors did not consider that the temperature within the building could be controlled adequately simply by means of a non-insulated roof painted white, but the roof was not, in fact, double skinned, and it consisted of aluminium sheets on the roof trusses. The space above the acoustically treated ceiling was not artificially ventilated. All the roof water was conducted to the ground drains in ducts and pipes. The scheme of ventilation relied on generalized movement of air throughout the engine room and the basements, by means of extensive window apertures and a system of aluminium air ducts and louvres.

208. The Authors were not aware of any particular difficulty due to the inequality in the lengths of the engine exhausts. The exhaust systems were capable of sustaining the higher temperature of the exhaust gases when the waste heat boilers were inoperative.

209. The reinforced concrete crane beams formed a part of the building structure.

210. As the Chairman had pointed out, inorganic grit was small in quantity, though even separate systems were liable to collect enough to cause trouble in disposal works if not removed, but Singapore sewage contained a relatively large quantity of woody fibrous materials with similar tendencies towards abrasion and settlement in the wrong place, and experience at the older works had shown the need for "grit" channels.

211. In-sewer chlorination was not seriously considered because of the cost and difficulty of control, but could be applied at a later date should the need be demonstrated. It was, however, to be expected that as flows increased, septicity of sewage arriving at Tanglin Road would diminish.

212. There was no danger to health from pollution of water in which prawns were cultivated, the fear being rather that the prawns, which were apparently particular as to environment, might suffer, and the reference to existing pollution in the river was to demonstrate that conditions in the prawn ponds would be little affected. No adverse effect had appeared to date.

213. The reference to shellfish had been misinterpreted. The shellfish beds were a good distance from the point of discharge and, as work by the Water Pollution Research Laboratory had shown, danger to health from contaminated shellfish could be safeguarded by cleansing the shellfish collected and, in this instance, this would be a more economical solution, should any concern be felt, than attempting to produce an effluent free from pathogens.

214. In reply to Mr Tattersall, the installed air capacity (4 cu. ft/min./lineal ft) was substantially greater than the normal total load of about 350 cu. ft/min. quoted in § 22. Experience at Derby had shown that air supplies in the range of 1–2½ cu. ft/min./lineal ft had little effect on performance, the lower figure being adequate. The aeration effect was incidental, and not much could be expected in the short period of detention in the channels.

215. The control of the vertical return sludge pump was by electrical resistance.

216. The choice of circular tanks followed from the climatic conditions and the consequent desire for quick and continuous removal of sludge from the floor of the tanks.

217. Facilities to remove separated water from the secondary digestion tanks were provided, using a rotating "search" arm from the control chamber, and, in view of the generous capacity of the biological treatment units, the separated water was returned without treatment to the main sump.

References

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