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The Chania-Sasumua water supply for Nairobi †

by

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Discussion

Mr H. J. B. Harding referred to a visit he had made to the site in January 1954, which was of added interest to him after being concerned in a tender for the work. In particular he wished to refer to earthfill.

103. Because the soil had had to be ploughed up for drying it had needed 30 acres of borrow-pit of which only 5 acres could be exploited at a time for excavation and compaction. However, the effect of this had been to produce a tilth which had made a material very favourable for spreading and compaction.

104. In Britain by contrast there were no dependable wet and dry seasons, and the handling of clays, particularly glacial clays, was a much more difficult affair and the material was apt to come away in large lumps when dug.

105. Mr Harding drew attention to the difference in borrow-pit procedures for dam building on the one hand and road making on the other. For dams, material usually came from borrow-pits in a wide area inside the reservoir, with plenty of space for movement or drying if required. Among recent Papers which had thrown light on this problem was that by Banks [15] on the Knockendon Dam.

106. In such circumstances it was possible to work over 30 acres and remove only 5 acres at a time.

107. In modern road work, in a densely populated country such as Britain, only a narrow width was available for cut-and-fill and time was held to be of extreme importance. There was no such space available for pre-drying a material.

108. Excavation was easy with modern plant and after so much excavation work on opencast coal there was a tendency to forget that compaction to a keen specification was a much more difficult operation to control and to obtain required results. The effect of rain could be devastating in a clay country such as Britain.

109. For compaction of clay there was needed strength, proper control, speed, and economy. In Britain, with no predictable climate, one or more of those features were not within the complete control of the engineer.

110. As plant steadily became larger and more costly, so did the pressure of salesmanship increase. This did not help those who had to control the fill by compaction tests, especially if vast capital sums had been invested in plant in order to move large quantities of earth very quickly.

111. The onset of rain would reduce progress considerably and disorganize a programme so that the initial capital cost became a very serious matter.

112. When he had visited the Chania-Sasumua site, the fourth phase had started,

† Proc. Instn civ. Engrs, vol. 9, p. 345 (Apr. 1958).

reverting to direct labour, and the plant could be stopped and started at will without involving a dispute.

113. In his Papers on the Muirhead Dam,[16, 17] Banks had pointed out that a 2% change in moisture content reduced the strength from 40 to 20 lb/sq. in., so that the material was very susceptible to quick change.

114. The modern motorways called for cut-and-fill on a scale not reached in the United Kingdom since the building of the railways. Settlement in a railway bank could be corrected by ballasting or filling with ashes, but no such settlement could be tolerated in a road bank where such corrections were not possible, and yet there was usually no space to aerate the embankment material before compaction.

115. Mr Harding referred to the difference between haste and speed. The roads would have to last 100 years. If, instead of spending 15 years in trying to design the road and then asking for it to be built in 18 months, 14 years were spent on design and 2½ years allowed for the building, the results would be better for all concerned.

116. In the current road programme, if a series of dry summers should occur, much boasting of achievement would follow, but if two more wet summers occurred, much "verbal blood" would be shed before the contracts were finally settled at the end of the work.

Mr J. M. Abbott described some of the problems encountered in the construction of the pipeline from the Sasumua Dam to Nairobi. He had been in East Africa for the first part of the construction of this work, and had later returned for 6 months of the emergency period but unfortunately had not seen the pipeline brought through to Nairobi.

118. His firm had constructed the first pipeline, from Ruiru, and this experience led to the belief that the chief difficulties would be in the transport and housing of the men, and supply of materials and pipes. The terrain to be covered had been difficult and there had been no access road to most of the line. All the access roads had had to be made by grader and bulldozer, and one of the chief difficulties had been how to move the men forward, with their housing, economically.

119. Small tents were provided so that the men could camp, with one or two men in each tent, and, after doing so many hundred feet of work, move forward. This had worked very well, because it meant that the men had not had much to carry, and they had to move forward fairly frequently. The transport of the pipes had been a different problem, because they had had to be hauled from the railheads to which they had been sent. Graders had been used to provide access from the roads to the villages, and then to the line itself. As soon as the pipes had arrived in sufficient quantity, they had been transported during the dry season, from January to March, when laying had begun.

120. The labour force had been almost completely Kikuyu, but almost the whole of this force had worked with the firm on a previous pipeline, and had been fairly continuously employed by the firm in and around Nairobi. When the Mau Mau situation became more serious, and the gangs had been driven from the forest areas, the work had had to be suspended and was restarted in November 1954 at the request of the Nairobi City Council.

121. Mr Abbott recalled some of the difficulties which arose through Mau Mau activities, and which included recruitment of fresh labour until the experienced men previously employed were allowed to return. He described some of the security arrangements made during construction of the 16-in. pipeline, and the concurrent work on the 24-in. pipeline which passed through the Kikuyu reserve.

Mr W. F. H. Dufour made some observations on the general design of the treatment plant and on the conditioning of the water prior to filtration.

123. The design was a straightforward one. The specification issued by the Engineers had emphasized the importance of simplicity and the plant installed was as simple as it could be to secure efficiency of treatment under all conditions.

124. The raw water entered the plant through a manually operated inlet penstock into a weir chamber for measurement. The flow to be put through the plant was decided daily by telephone consultation with the Superintendent in Nairobi and, once set, that flow remained constant. The water passing over the weir discharged into a mixing chamber where the coagulants were added and then to horizontal-flow sedimentation, tanks and rapid gravity filters. Horizontal-flow tanks had been selected because of the uncertainty of the site; vertical-flow tanks would have required more excavation. After filtration, the water was treated for pH correction and chlorinated by the chloramine process.

125. The treatment had had to be designed before any truly representative samples were available. The few samples available from the stream had indicated that the water would respond quite well to coagulation by alumina but that the addition of an alkali might be necessary at times. It was decided to provide for soda ash for this purpose and to use the same chemical, in preference to lime, for pH correction of the filtered water. In East Africa, the relative costs of soda ash and lime were more favourable to the former than in the United Kingdom.

126. The plant had been put into operation in June 1956 and in February 1957 Mr Dufour had had the opportunity of visiting it. At that time, the treatment being applied was between 40 and 50 p.p.m. of alumina and about 20 p.p.m. of soda. The raw water had a colour of 70 p.p.m., slight turbidity, and a pH of 6·7. A good floc was being formed and an excellent filtrate produced. The soda ash was not, in fact, required and was cut out with virtually no difference in the performance. It had been interesting to observe the behaviour of the water in the settling tanks. The water was very effectively flocculated by the movement induced hydraulically by the design of the inlet into the tanks and pin-point floc could be seen rapidly growing into large floc. The floc level became lower and lower along the length of the tank, as was to be expected, and halfway along it was no longer possible to distinguish it. At the outlets, however, a steady stream of large floc particles could be seen passing over the weir and along to the filters. The proportion of floc which was behaving in this way was not very great but was adding an unnecessary load on the filters.

127. A few weeks later an engineer from the Company had spent 2 weeks at the plant to make a thorough check of all the equipment and treatment. As soon as he arrived, he had tried the effect of bicarbonate-modified sodium silicate as a coagulant aid and the result had been remarkable. After some experimenting with dosages, it had been found that approximately 30 p.p.m. of alumina and 4 p.p.m. of silicate produced a good floc and no large particles of floc passed over into the settled water as had occurred previously. It was possible at the outlet end to see the sludge on the floor of the tank through a water depth of about 10 ft. The filter runs between washings had increased in length and the overall result had been highly satisfactory. It had been an outstanding example of the great aid of modified silicate for coagulation. From the point of view of cost, which also was important, there was a saving of between 4*s* and 5*s* per million gallons in coagulant alone, even based on the relatively high cost of the silicate and bicarbonate bought in small quantities in Nairobi. In addition, there had been a saving in the soda dose to the filtered water because the pH had not been depressed so much and the filter washing would be less frequent, thereby saving filtered water for washing. Thus there was a handsome overall saving in the cost of treatment.

128. The raw water was chlorinated and it was noticeable that there was no sign at all of any growth in the tanks or filters. The chloramine treatment to the filtered water was set to produce a residual of 0·5 p.p.m. of chlorine in the water going into the pipeline.

129. Reverting to the flow control through the plant, Mr Dufour explained that it was so designed that whatever flow was delivered to the filters was divided equally between them. When one filter was shut off for washing, the flow through the others in service was automatically stepped up and the total outflow remained the same as the total inflow. An important point here was that the whole of the chemical dosing

equipment could be manually controlled and no automatic proportioning system was necessary, thereby keeping the equipment as simple as possible.

130. In Great Britain there was a trend towards fully automatic filter operation, in which that country was quite certainly well ahead of all others, but those who had seen the electrical master controllers involved might well be frightened by the multitude of wires and relays. The equipment was not complicated to those who understood it, but it was of a specialized nature. It very often paid to put in such automatic equipment in order to save labour in plant operation and in the United Kingdom specialists were always available for servicing the automatic equipment. However, to install it anywhere without adequate service behind it would be asking for trouble. For example, in East and West Africa it would not at the present time be feasible to use such equipment. On the other hand, a plant with fully automatic filter control was now being built in Trinidad and this had been made possible because the telephone company there, whose automatic exchanges incorporated equipment of a similar nature, would be able to undertake servicing.

Dr T. P. O'Sullivan noted that the figures for evaporation losses in Table 2 seemed to be somewhat less than 48 in., and showed that those losses were very much reduced owing to the high altitude.

132. The Authors would realize the difficulty of correlating test figures with figures on a large surface. On a large surface the evaporation was affected to some extent by the wind. A cross-wind became saturated. There might be a slight reduction, but it would not be large. For a scheme near Kano, in Northern Nigeria, at an altitude of 1,500 to 2,000 ft, the expected evaporation was 70 to 80 in. Probably the lower humidity and much lower altitude accounted for the difference.

133. Dr O'Sullivan then referred to seepage and eventual loss due to siltation. He had conducted some researches on siltation and he had been shocked by the record of a reservoir built in New Mexico some years ago, which had silted up to the top and been written off in 10 years.

134. Could the Authors give a little more information about the conditions obtaining at peak flood discharge, with discharges of unusual magnitude; i.e., the discharge to the spillways and so on. In another part of Africa it was known that there had been difficulty with big floods; what was likely to take place at Sasumua?

135. In § 96 the total cost of the scheme was given as about £2,400,000, of which £800,000, or about one-third, was for the pipeline. The Authors had mentioned that difficulty was caused by the pipes being damaged, and Dr O'Sullivan himself had had to face this problem, and also that of transport charges. From Lagos to Kana was about 1,000 miles by rail, and for £500,000 worth of pipes the transport charges would be well over £100,000. There was the problem of whether to use steel or cast iron, but what were the possibilities of using prestressed concrete pipes? There had been a classic case of failure in Canada some years ago, where electrolytic action had caused alarm, but in Tanganyika a very successful pipeline 120 miles in length had been laid to the coast at an economic figure.

136. The extent to which a pipeline could be left uncovered depended to some extent on the country. In Kenya, if left uncovered, it might be damaged by Mau Mau or big game, but in other countries if it could be left on the surface that might be an advantage. With high pressure there would be an anchorage problem at sharp bends.

Mr Bernard Whitteron said that it was stated in § 10 that compensation water plus losses accounted for 2·1 m.g.d. out of a total yield of 9·65 m.g.d. Most compensation-water discussions related to reservoirs in Great Britain where there still persisted the outdated form of assessment developed to meet the needs for driving mills immediately downstream. Since, in the case mentioned in the Paper, the award had been made in an overseas country where different circumstances applied it would be useful to have on record the quantity of compensation water and the basis on which the decision had been made.

Sir Hubert Walker asked the Authors to give some indication of how, or by whom, the 14 cusecs had been calculated, and also for how long it was estimated that 7·7 m.g.d. would suffice for a growing town such as Nairobi.

Mr J. C. Mobbs asked if damage to the steel pipes used in the pipeline, particularly at the port of disembarkation, Mombasa, had been mainly to the pipes themselves or to the bitumen lining and what had been the effect on the bitumen of the strong sun at the port, where the pipes might have been lying in the sun for a considerable period? At least one firm had recommended that the pipes for another project in the tropics should be manufactured of steel in the country where they were required and lined with concrete rather than bitumen.

The following contributions were received in writing.

Mr H. V. Lawrance questioned the admissibility of the method of calculating the maintainable yield from rainfall, as outlined in §§ 19–21. It would appear that the method assumed that run-off bore a linear relation to annual rainfall or to the sum of rainfall over 2 or 3 dry years. What evidence was available to substantiate this method?

141. So far as the Union of South Africa was concerned, there was clear evidence to show that there was poor correlation between annual run-off and annual rainfall.[18, 19] Midgley[20] had contended that, on an annual basis, run-off tended to vary as the cube of the rainfall. He had, however, pointed out that a combination of factors might arise, making the index higher or lower than three. Three was, however, a reasonable average.

142. Kanthack [21] had also considered the relation between rainfall and run-off in central southern Africa where the conditions probably approximated more closely to those, which the Authors had described than the references cited in respect of the Union. Kanthack had based his analyses on daily rainfall, excluding all falls less than 0·10 in. In addition he had made allowance for dry periods during the rainy season and for the dryness of the catchment at the end of the previous hydrographic year.

143. Mr Lawrance was therefore of the opinion that to use Fig. 4—the departure from mean annual rainfall—as an expression of the departure from the mean of annual run-off was likely to lead to misleading results. If the gaugings referred to in § 9 were plotted in a similar fashion to Fig. 4 this contention might probably be demonstrated.

144. Mr Lawrance suggested that the 1947 gaugings might be extended backwards until 1942 by logarithmic plottings of the P.W.D. and Chania-Sasumua gaugings, according to the method suggested by Langbein and Hardison,[22] thus achieving a 13-year record by 1955. Another line of attack to determine annual run-offs would be the approach adopted by Kanthack (*supra*), using the Lari Forest gauge for daily rainfalls. The massed run-off curve could then be analysed with greater confidence.

Mr Henry Grace observed that §§ 53–67 on plant and procedure for earthfill and laboratory control of earthfill were the most original and useful parts of the Paper.

146. It might be thought that the problem of drying out the soil prior to compaction was peculiar to Sasumua, but Mr Grace believed that similar cases were likely to be encountered both in the United Kingdom and abroad. British soils of the sandy and gravelly types, when excavated from below the water table or during periods of wet weather, invariably existed at moisture contents well above the optimum. The climate at the Sasumua site appeared similar to that of an average British summer.

147. He thought that the Paper gave a very useful guide to engineers in the U.K. who were faced with earthworks which, in order to meet the specification, had to be carried out at controlled moisture contents.

148. It would therefore be of interest if the Authors could give rather more detailed information on the conditions when drying out became practical. The speed of drying out depended on the temperature and relative humidity. Could the Authors say over what ranges of temperature and humidity drying out was found to be a practical proposition? What percentage of the time did the sun shine during the drying out period?

Could they say how many passes of the various machines such as the roto tillers, ploughs, and disks were on an average required to reduce the soil to its optimum? What was the average cost of the drying out and how long did it take? Looking at the earthfill progress chart in Fig. 8 it appeared that even during the periods marked wet or humid quite considerable drying out was possible.

149. Mr Grace was interested to note that heavy compaction plant had been used. All too often attempts had been made to compact soil to its maximum dry density using relatively light plant. This had led to an excessive number of passes which in turn had led to delays and other difficulties. It was his experience that if the required density could not be obtained in about ten passes of the roller, further rolling produced only small increases in density. The Authors stated in § 59 that seven passes of each of the rollers was required. As four rollers had been used it appeared that twenty-eight passes had been given to each area. This seemed rather an excessive number. It would have been more economical to have had one 70–80-ton pneumatic-tired roller with high tire pressures in place of the three relatively light pneumatic-tired rollers. Did the Authors agree with this?

Mr F. L. Duquemin observed that the Authors mentioned that it had been necessary to place fill wide of the design profile of the embankment to ensure compaction over the whole section. Was this not owing to the impracticability of rolling the edge at the top of the 1–2 (down-stream) slope with the comparatively heavy plant used? Could the Authors estimate what extra cost the operation of trimming the slopes by dragline had added to the mean cost of fill place?

151. As the embankment had approached its full height and the available placing width had become less, i.e. above the foundations of the wave wall, the rate of placing had become very low. The spreading of the soil had had to be carried out as a separate operation from the rolling, and the plant could only be used for part of the time it was available. This must have resulted in a great increase in the cost of the last 20–30,000 cu. yd of fill.

152. The rollers and their tractors at Sasumua had only been able to operate over a limited range of soil moisture content. If the moisture of the fill varied too much on either side of the specified optimum moisture content the rollers had bogged down in the mud or the dust. Could the Authors estimate the moisture content range through which the rollers could operate? How much did it vary from the range in which the soil had actually been placed?

153. The Authors stated that in general seven passes of the roller teams were required to give complete coverage and the required density. Were figures available of the coverage and density achieved with less than seven passes? Would it not have been practicable to build an embankment with the soil in the physical state which would have resulted from placing the soil at the optimum moisture content for the compactive effort of say four passes of the equipment used?

154. Was there not a case for using construction-plant performances as an additional factor in the design of earth embankment? The embankment containing the minimum amount of material to ensure stability was not necessarily the cheapest to construct. Was not the plant optimum moisture content and consequent dry density a better basis for the specification than the quite arbitrary Proctor optimum moisture content? Rather than slavishly simulate on site what could be achieved on a minute scale in a laboratory, it would seem to be better to design an embankment to a specification which could readily be achieved in the field. That, probably, would result in a wider embankment, which, as at Sasumua, might be limited by topographical conditions, but soil sampling and testing, rather than being used as an unwieldy method of control, would then give a general indication of the physical properties of the embankment, which, together with other data, from pore-water pressure cells, etc., would enable modifications to be made to the design, if required, on the "design as you go" principle.

Mr FitzGerald, in reply, said that he had been primarily concerned with the construction problems and the field control. Mr Harding, in referring to soil testing, seemed to think that because the work had been done by direct labour the soil testing had not been rigid, or, in other words, that the consulting engineers had not been exacting. Nothing could be further from the truth; they had been twice as rigorous as they had been with the former contractors.

156. Mr FitzGerald agreed with Mr Harding that nowadays there was a tendency for excavating equipment to get bigger and bigger, and added that the rollers were also tending in the same direction. He would not care to use a 200-ton roller, or even a 100-ton roller, taking the view that 50 tons was about the limit where the surface of an earth dam has to be maintained at an outwards batter from the centre to throw off rainfall. It was possible to keep up with a great deal of excavation plant with 50-ton rollers on straight stretches, or with, in the case of road construction, 100-ton rollers. Admittedly in the United Kingdom the moisture content could complicate the matter very greatly, because one might have all the soil spread and then the heavens would open, so that by the time it was possible to spread it the excavation plant would have been standing idle for some time.

157. Mr FitzGerald also agreed with Mr Harding that as the size of the earth-moving plant used on earth-dam or road construction was increased, so also would the number of personnel engaged on soil testing have to be augmented to provide the necessary control.

158. Mr Harding had referred to the hiring of plant. It had been very useful to call on the firm which provided it to supply plant, but, with all respect to them, some of that plant had been very tired!

159. In conclusion, he thanked Mr N. Pleming, of Associated Industrial Consultants Ltd for permission to leave his work in Dublin to attend the meeting.

Mr Dixon, in reply, endorsed Mr Dufour's plea for simplicity in design of filtration plant. He had, of course, been guided in this by the wishes of Mr Bridger, then City Engineer of Nairobi, who had been adamant that everything should be as simple as possible. Mr Dixon thought that that was quite right. The problem of getting qualified people to run treatment works both for water and for sewage was almost insurmountable. If a large sum of money was to be spent on modern plant one should be prepared to spend a small amount of money annually on the expert staff necessary to run it. The employment of a chemist or water biologist with specialized experience was well worth while, because he could, on occasion, save far more than the amount of his salary in chemicals and maintenance costs.

161. The sampling of water was not easy for an impounding scheme, because before a dam was built all that one had to sample was the stream, and in the case of the Sasumua the flow had been negligible in the dry season, while in the wet season it was substantial with a fair load of silt. It was only after impounding that the water settled down and took up, in the early stages of impounding, organic matter. The oxygen was denuded at the lower levels, and there were all sorts of secondary problems which did not occur at all in stream water.

162. The Authors were convinced that the evaporation losses at the high level of over 8,000 ft would be less than they were, for instance, at Dodoma, in Tanganyika, at about 4,000 ft where the figure was about 120 in. per annum as deduced from observations on a reservoir. At Nairobi (6,000 ft) evaporation was in the region of 73 in. on a standard pan. Mr Dixon quoted Dodoma because that might possibly be comparable with Dr O'Sullivan's problem at Kano and therefore helpful. One striking fact about the Ruiru evaporation losses was that from the date that the reservoir had been impounded the annual loss had decreased. He was awaiting further reports to make sure that that was a real occurrence and not just a mistake in the figures. If it proved to be true it would be most interesting; it meant that before impounding the river there was a higher loss, but after impounding, when the atmosphere was more moist, the loss was less. There was no doubt that in the unimpounded condition, at the lower level of

Ruiru, there had been substantially more evaporation than at Sasumua. It is too early yet to say whether a similar reduction has taken place at Sasumua.

163. With regard to seepage losses, reference should be made to §§ 68 and 69 of Professor Terzaghi's Paper*.

164. With regard to silting, Mr Dixon had for some years before legislation had been passed in Kenya, urged the authorities to take measures whereby catchment areas would be safeguarded both from pollution and from the ill-effects of bad cultivation and other maltreatment of the land which resulted in soil erosion. The authorities were, he believed, fully alive to this, and he understood that constructive steps were being taken. The prospect, of course, was unhappy for nearly all reservoirs, and it was a matter which must be dealt with wherever possible. One thing which helped was to see that the banks of streams in the catchment area were grassed and that no cultivation whatever was permitted in their immediate vicinity. That would at least keep the trouble within bounds.

165. Discharges of unusual magnitude were not very frequent. The biggest discharge which they had had at Sasumua had been about 1,200 cusecs, but it did not follow that they would never experience the much larger flows over the spillway for which they had made provision. With an earth dam it was better to make the spillway on the large side rather than to attempt to design it down to fine limits. A method which was worth using as a check was the statistical method of extreme values by Gumbel, but adequate data were usually lacking. A discharge of 2½ times that appropriate to a catchment area in Great Britain as computed by the method of the "Interim Report of the Committee on Floods in Relation to Reservoir Practice" had been reported in Southern Rhodesia.

166. The prestressed pipe which had been referred to had been laid from Mzima Springs to Mombasa, not in Tanganyika, and he believed that its performance was adequate. The pipes had been made in Kenya; it was necessary to make them on the spot to save transport and to avoid damage. It would have been out of the question to use them from Sasumua to Nairobi, because of the extremely rugged nature of the terrain. Part of the reason for the pipeline costing one-third of the total cost of the scheme was that the lower end was a 24-in. pipe, which was the beginning of the next phase, on which a start was to be made at the end of 1958. Another pipeline was to be laid from Sasumua to connect to the 24-in. pipe and the combined carrying capacity will thus be increased to 14 m.g.d. The treatment plant at Sasumua was also to be augmented.

167. Elephants and other wild animals had to some extent been a problem, which was one reason why the pipe had had to be buried. Decoy tracks had been built round some of the more obvious places, because game tracks in a forest were the highways. There was a danger that a pipeline might become a highway, and so, both for convenience in construction and maintenance and to discourage animals from using the pipeline as a game track they built other tracks round about and tried to block easy access to the pipe track.

168. As much of the pipeline as possible had been buried; but in another case, in Sierra Leone, a large part of the pipeline had been built above ground using Johnson Couplings, which were themselves anchored to the piers, and wherever there was a bend, vertical or horizontal, those particular piers were designed to take the thrusts which arose. The anchored Johnson Couplings were, Mr Dixon believed, the invention of his late senior partner, Guy Howard Humphreys, and they seemed to work very satisfactorily.

169. The basis of assessment for compensation water had always offended Mr Dixon, as an engineer, because he hated to see very expensive structures put up for the sake of interests which made little if any serious use of the compensation water. He had analysed the dry-weather flow on the Chania when the statutory application was being prepared and the average over a month had been as little as 2·16 cusecs and he had

* Proc. Instn civ. Engrs, vol. 9, p. 369 (Apr. 1958)

recommended that that flow should be regarded as the proper compensation water to be put into the stream. The departmental decision, which had not been open to argument, had been that 5 cusecs should be given. He contended that it would be far sounder to pipe any compensation water required for genuine use over the dry-weather flow instead of letting it run to waste. If controlled river flushing is required in addition to flood water discharges over reservoir spillways, it can usually be arranged and it would be more effective than a steady flow of compensation water.

170. In reply to Sir Hubert Walker, the figure of 14 cusecs was laid down by a Committee appointed in 1945 by the then Nairobi Municipal Council and the Government of Kenya. A more likely increment, on present knowledge, would have been 32 cusecs by 1975. The addition of 14 cusecs from a new source when added to the sources in being in 1945 would have sufficed only until between 1960 and 1965. It should be said, however, that the figure of 14 cusecs had been fixed when the rate of growth in demand was even more conjectural than it is today.

171. The lining of pipes (§ 139) was a matter which caused concern in tropical countries, where pipes were liable to be left lying out in the sun for a considerable time. There had been a notable failure of the internal lining in pipes which had been delivered for the Aden water supply, but the conditions there were much more extreme than at Nairobi. The maximum temperature at the altitude of Nairobi was not very great, and if the pipes were whitewashed a good deal of radiation was reflected and the pipes did not reach such a high temperature as they would otherwise. Some 30-in. pipes had been delivered in Trinidad in 1946 and they had not been buried in the ground until 1957. There had been some repair work to do, mostly at the ends, but it had not been excessive.

172. The damage to the steel pipes had been principally the result of rough handling at the Port of Mombasa and had taken the form of dents and deformation of the ends of the pipes. This damage had been accompanied by damage to the bitumen lining and sheathing but the bitumen had not suffered any effect from the sun. Thatched shelters had been used at pipe dumps. Regarding the use of pipes manufactured from steel sheets in the country where they were required, Mr Edington was currently investigating that very point, but purely from the point of economy, since the freight on flat sheets was less than on pipes and the loss by damage to the pipes was eliminated. Preliminary figures indicate that pipes fabricated in the country in which they are required would be cheaper than imported pipes. With modern X-ray and gamma-ray testing equipment, quality should be no problem.

173. It has not been possible, in the time available for preparation of the Authors' reply, to do justice to the points raised by Mr Lawrance, but it was hoped in due course to submit some further analyses on the lines which he had suggested.

174. There had never been any serious difficulty about drying the soil (§§ 146–148) so long as the weather was suitable for placing, i.e. so long as it was not raining. The drying out of the soil had been facilitated by the presence of drying winds almost as much as by the direct rays of the sun. In other words temperature and humidity played a minor part. That was not to say that the soil had not dried out faster when there was a strong sun and a stiff breeze but even on a dull day with no wind, drying had not been a serious problem so long as rain was not actually falling. During the dry season proper the sun had shone about 75% of the time each day, while during the remainder of the year it probably averaged 25%. However, considerable drying was also known to have taken place at night when conditions had been favourable. Table 7 gave some relevant information.

175. The "agricultural operation" described in § 57 was not really complicated. In fact the heavy ripper had been used first to break up the soil into large lumps, then a spike-toothed or disk harrow and reduced the size of the lumps, then rotary hoes had broken down the lumps down to about 3-in. maximum size. The ripper had made only one pass, the harrow one or two passes, and the rotary hoes between four and six passes. The hoods had been taken off the rotary hoes to increase aeration. It was made clear in § 58 that the locally made rubber-tired roller and the pneumatic-tired

TABLE 7

Month	Earthfill placed: cu. yd	Range of temperature: °F	Range of humidity at 9 a.m.: per cent	Sunshine range a.m. p.m.	Monthly rainfall: inches	Number of wet days
Mar. 1954	58,000	76 to 37	83 to 40	9.55 to 4.10	2·37	8
Apl.	3,500	71 to 46	100 to 58	7.40 to 0.20	13·33	27
May	Nil	70 to 45	100 to 68	7.35 to 1.00	12·51	28
June	Nil	68 to 42	95 to 55	7.50 to 0.10	7·61	23
July	15,500	69 to 43	100 to 70	5.00 to 0.02	3·26	14
Aug.	11,000	68 to 42	100 to 53	6.30 to 0.05	2·02	17
Sept.	48,000	68 to 44	100 to 57	8.10 to 0.10	2·46	11
Oct.	49,000	72 to 41	93 to 46	8.50 to 0.40	2·30	15
Nov.	18,000	69 to 42	100 to 51	9.45 to 3.50	3·43	20
Dec.	31,000	73 to 40	93 to 51	No readings from 13.11.54 to 6.1.55	2·34	8
Jan. 1955	73,000	75 to 33	91 to 47	10.00 to 5.00	0·93	9
Feb.	44,000	77 to 35	88 to 48	9.50 to 0.35	5·12	13

tractor have subsidiary units and it was incorrect to assume, as Mr Grace had done, that those two units had always been used along with the 20-ton sheepsfoot and 45-ton rubber-tired rollers. The two subsidiary units had been used only when fill was being placed at maximum rate and had resulted in one or two less passes of the team being required. It would be fair to say that the average number of passes had been between 15 and 20 rather than 28. The relatively high number of passes given had been primarily to ensure complete coverage, since considerable quantities of soil had been placed at night when adequate control was otherwise more difficult. One heavy roller alone, however, would not have provided this coverage. A heavier roller would have reduced the number of passes required but it was not thought that this particular soil would have compacted to 100% Proctor with less than 15 passes of one 70- to 80-ton roller. The reason why lighter equipment was used was in order to be reasonably sure of being able to sell the equipment in Kenya on completion of the works.

176. The extra cost of trimming the slopes by dragline (§ 150) was negligible. The actual cost of operating the dragline itself was not more than £500 and the soil which it had removed from the slopes had been cast on the surface of the bank and compacted, so that no loss of material had occurred. Mr Duquemin was correct in assuming that the reason why fill had had to be placed wide of the design profile was the impracticability of compacting right to the edge of a 1-in-2 slope. It was agreed that the cost of the last few thousand cubic yards of fill was greater than the fill in the body of the dam but that was only one of the parts of the dam where fill had been expensive. Other parts were the fill first placed in the river bed, fill around bridge piers, and generally fill adjacent to any structure such as the spillway crest. In § 152 Mr Duquemin had mentioned rollers bogging down in mud or dust. No mud or dust had ever been brought into the dam. Soil had always been adjusted to optimum moisture content prior to the placing in the embankment.

177. The rollers would not operate at all well outside the range 40%–55% but had been really effective only in the range 43%–53%. In general the optimum moisture content for the sheepsfoot rollers had been rather lower than that for the rubber-tired rollers.

178. Optimum density had been obtained with as few as four passes of the compacting equipment, but as previously stated, adequate coverage had required rather more passes. Four passes only of the rollers might have resulted in a satisfactory structure, but the risks of under-compaction or absence of complete coverage should not be taken.

179. In §§ 153, 154, Mr Duquemin appeared to be suggesting that design of earth dams might be related to economic performance of plant available rather than an arbitrary density based on laboratory tests. The objection seemed to be that it was never known in advance what type of plant the successful contractor would be using and Mr Duquemin's suggestion boiled down to specifying a density which could be easily achieved by the lightest compacting plant in current use. That would be unwise, and, as Mr Duquemin himself had stated, would result in flatter slopes to achieve stability and thus in considerable extra expense. The use of compacting equipment of the type used at Sasumua, i.e. 50-ton rubber-tired rollers and 20-ton sheepsfoot rollers, should ensure economic achievement of 100% Proctor in any soil provided it was placed at optimum moisture content and since that type of compacting equipment was coming into general use, even in England, there was no need to reduce the specified density below 100% Proctor at the expense of extra material in the bank owing to flatter slopes.

180. Unless the plant to be used was specified, it would appear to be difficult to predict the plant which the successful tenderer might use. Equally, it would be difficult to predict what the eventual compaction characteristics of the plant would be. The Proctor test on the other hand was a relatively straightforward test, and, more important, was a generally accepted standard. In any event, if doubts were entertained as to the suitability of the only available materials, modified Proctor could be specified which, to any experienced contractor, meant extra heavy equipment.

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