*Discussion on Paper No. 6703**

Cameron Highlands hydro-electric scheme

by

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and

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Mr J. K. Hunter (Sir Alexander Gibb & Partners) said that in reading the Paper he had been struck by the close similarity between the conditions described in the Cameron Highlands, which he had never visited, and those in the Adams Peak District of Ceylon, with which he was well-acquainted. This similarity had led him to compare the recently completed scheme described in the Paper with a rather similar one in Ceylon which had been planned just after the First World War by, he believed, the late Evan Parry and which, after a somewhat chequered history, had eventually been brought into service about 12 years ago.

100. It seemed all the more natural to make this comparison because both schemes had been carried out by the same two firms of British Consulting Engineers. Because of that they offered a good illustration of some of the technical advances which had been made during the last 30 or 40 years in the planning and execution of hydro-electric schemes.

101. Both developments were essentially high-head run-off river schemes utilizing the waters of a mountainous region clothed in dense tropical jungle and offering poor facilities for storage. In both schemes the lower slopes of the valleys had been planted up in tea over the last 60 or 70 years and in consequence, had been denuded of forest cover. Anyone who was acquainted with the tea districts of Ceylon—and he felt sure that it applied equally to the Cameron Highlands—would know that the clearing of the original forest cover from the steep hillsides had exposed the rock to heavy erosion. As a consequence, the rich topsoil had long since been washed away into the valley bottoms where it enriched the local paddy fields, while the rivers continued to carry, when in flood, a high load of suspended material.

102. In this respect, the Adams Peak District was probably rather worse than the Cameron Highlands because the planting up of the area had been started at an earlier stage and at a time when no-one paid heed to the problem of soil erosion.

103. However this might be, it was clear from the Paper that the suspended loads in the streams supplying the Jor power station were matters of serious concern to the engineers. Such problems were by no means confined to Ceylon or Malaya and it would be interesting to learn how successful had been the measures adopted in the case of the Cameron Highlands scheme to mitigate them.

104. The latter development had only just been brought into operation while the first stage of the Ceylon scheme, which was based upon a head-pond at Norton Bridge, had been in service some 12 years and it was therefore reasonable to suppose that considerable operational experience had, by this time, been accumulated.

105. Unfortunately, power authorities were not usually very forthcoming in passing on to their consulting engineers the benefit of their operating experience.

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* *Proc. Instn civ. Engrs*, vol. 26, November 1963, pp. 387–424

However, it was only by studying the results of such experience that advances could be made and it was therefore important to the engineering profession that information of this kind should be made generally available.

106. From the figures given in the Paper, it seemed that the usable capacity of the Ringlet Falls head-pond was only about 2% of the average annual inflow into the reservoir, although in terms of the run-off from the direct catchment area it was nearly 4%. The total volume of suspended material entering the reservoir was therefore likely to be significant in relation to the usable storage. The conditions of Norton Bridge were even less favourable, the usable storage representing only about 0·1% of the annual run-off. In such conditions it was probable that a large part of the live storage had been lost within a comparatively short time, thereby reducing its value as a settling pond and increasing the amount of solid material which passed through the turbines.

107. It might be supposed that in conditions such as those at Norton Bridge, a state of equilibrium would be reached after a time. All suspended material entering the reservoir would then either be carried over the spillway with the flood water or passed through the tunnel and on to the power house. The wear on the nozzles and buckets was thus likely to be very high and this effect would be combined with that due to the loss of daily pondage. The loss of pondage which had already occurred could hardly be recovered, but the suspended load passed on to the turbines would of course be reduced in the future when the second stage of the Adams Peak scheme, which included a seasonal reservoir, was carried out.

108. However that might be, it would be interesting if the Authors could pass on some of the experience which they had gained in Ceylon and the manner in which that experience had been applied in designing the Cameron Highlands scheme.

Mr A. H. P. Cardew (Central Electricity Board, Federation of Malaya) thanked the Institution for allowing him to speak in the discussion. He was in England on leave prior to retirement, and it had been suggested that he should attend the meeting and say a few words about the early history of the scheme.

110. As long ago as 1938, when he had first gone to Malaya, there had been talk of hydro-electric power in the Cameron Highlands area. In 1941, a few months before the outbreak of the Japanese war, two of the Electrical Department's engineers —Mr L. G. W. Ward, who subsequently died in captivity in a Japanese camp, and Mr J. H. Sumner, now the Board's chief engineer in the hydro-division and project engineer for this scheme—carried out some investigation and some river measurements, together with investigations in the Cameron Highlands area of the main rivers Telom and Bertam.

111. Naturally, the Japanese war interrupted any attempt at that time to carry the scheme further. In 1945 there was not much time to do anything about it, nor was there much time for some years afterwards. But as soon as possible Mr Sumner had got down to further investigations, but only to a very limited extent as everyone was doing two or three jobs. It was not until 1947, when unfortunately Mr Sumner was in Japan on a reparations commission, that it had been possible to secure the services of Mr B. Gates, a New Zealand engineer with considerable experience of small hydro-electric schemes. He had undertaken some field investigation in Malaya.

112. This was the only time when Mr Cardew had been closely associated with the scheme, which he had been looking after in Mr Sumner's absence. Mr Gates lived in the Cameron Highlands for some years and looked for a scheme which would bring the power into the west side of Malaya. A range of mountains ran down rather to the west of the centre of the country, and most of the more industrialized areas, and the bigger towns, were on the west. This was where most of the electric load was and where the Board's central network was. Previous schemes had tended to run down to the east. The tentative idea had been to develop the Telom or Bertam

rivers towards the east in Pahang, which was getting further away from the load centre and would have meant transmission lines crossing many miles of completely uncharted jungle.

113. Mr Gates had conceived the broad outlines of the present scheme. He had had the idea of bringing two rivers, separated by a large mountain, together, and then transferring them by a tunnel through another mountain into a catchment area of a third river some 2000 ft below. This had been an original concept and a brilliant one.

114. Unfortunately, shortly after Mr Sumner's return from Japan at the end of 1949, when he resumed charge of the scheme from Mr Cardew, he had been with Mr Gates investigating in the Cameron Highlands when Mr Gates had been killed by terrorists. The presence of those terrorists from the middle of 1948 onwards had held up the scheme.

115. After Mr Gates' death, the scheme had been completely held up and nothing had been done from early 1950 until late 1952, when the security position improved a little. The services of another civil engineer, Mr P. G. D. Shallow, had been secured. From then on things had proceeded fairly rapidly, and the rest of the story was told in the Paper.

Dr J. R. Rydzewski (Southampton University) wished to enlarge on § 57 of the paper, where mention was made of photoelastic studies on normal slices of the buttress head of the Ringlet Falls Dam.

117. The object of the tests was to discover how effective the wedge action of the closing wedges was under two distinct physical conditions. In the first it was

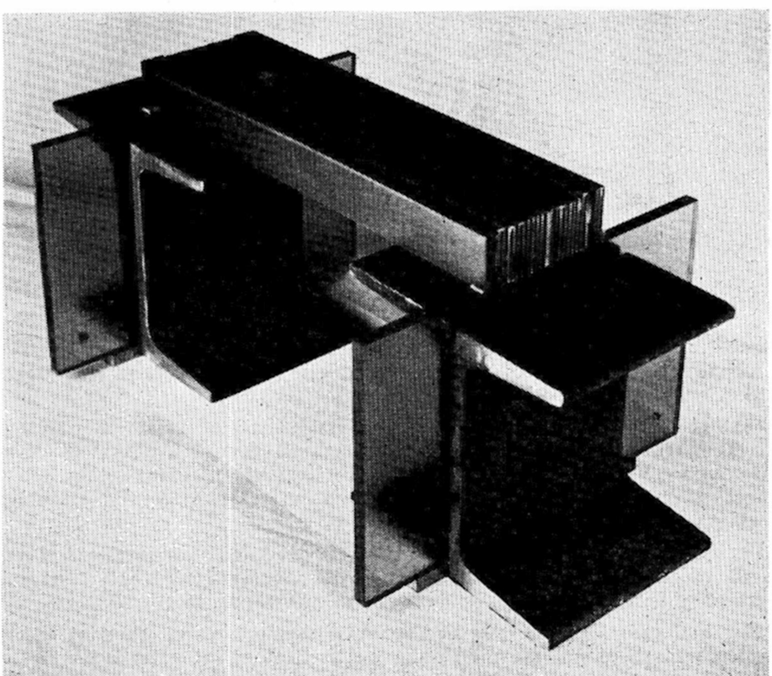

FIG. 21: MODELS OF BUTTRESS HEAD SLUICE UNDER LOAD

FIG. 22: PHOTOELASTIC FRINGE PATTERN FOR THE ASYMMETRIC CASE

assumed that no friction existed between the wedges and the buttress head, while in the second, one of the wedges was taken to be fully bonded to the adjacent buttress heads.

118. The experiments were carried out on models made of Araldite CT-200 epoxy resin, using the 'frozen stress' technique, in which the model is loaded at an elevated temperature (130°) from which it is slowly cooled with the loads acting. In this manner the photoelastic effect is 'frozen in' and can be observed in polarized light, revealing an interference fringe pattern.

119. The water pressure was simulated by the dead weight of narrow steel strips, laid side by side and spanning between two models, as shown in Fig. 21. The resulting fringe pattern, for the non-symmetrical case, was shown in Fig. 22.

120. Full details of the tests had recently been presented,[5] showing that the designers were successful in avoiding tensile stresses along the water face.

121. The tests took less than three weeks to perform and served as a good example of how well-chosen experimental methods could be of rapid assistance to the designer.

Mr A. E. Seddon (Assistant Director, Hydraulics Research Station, D.S.I.R.) said that the Authors had mentioned the hydraulic model investigations carried out in 1957 and 1958 at the Hydraulics Research Station. These were concerned with the design of the spillway and stilling basin at Ringlet Falls Dam[6] and the weirs and tunnel intake on the Sungei Telom,[7,8] and they were mentioned in §§ 61, 70 and 71 of the Paper. His colleague, Mr A. F. Whillock, had carried out the investigations and would later show a short film taken during the course of the work on the dam and stilling basin. Mr Seddon proposed to speak briefly about the Telom investigation.

123. The layout of the Telom weirs and tunnel intake had been shown in Fig. 16(a), and the site was at the second left-hand bend in the Sungei Telom shown in that diagram. The main weir across the river was intended to divert normal flows of up to about 300 cusecs over the sideweir on the outside of the bend and into the dropshaft and tunnel; whereas at flows greater than about 300 cusecs the main weir was overtopped and only part of the flow was diverted. The Sungei Kial, a downstream tributary of the Telom, provided additional flow upstream of the sideweir and discharged into the river through the Kial tunnel and the Kial channel.

124. The weirs and intake were sited so that large quantities of sand and gravel transported by the river would tend to be diverted away from the sideweir by secondary currents caused by the river bend. The performance of the layout and the effectiveness of secondary currents in this respect were the main subjects of study in the H.R.S. investigation and, as the Authors had pointed out in § 70 (*c*), the siting of the Kial channel was particularly important. A 1:30 scale model was used, and the model area was about the same as the area shown in Fig. 16(a). The tests were concerned mainly with normal discharges, but performance data were also obtained for discharges up to the design flood of 33 000 cusecs. In the proving tests comparisons were made between the transport of model and prototype bed materials, based on prototype data supplied by the Central Electricity Board of the Federation of Malaya. It was concluded that, in general, a sand of 0·17 mm mean size was the most suitable model bed material, although additional tests were carried out using crushed perspex and wood grains.

125. In § 70, the Author had mentioned that a stepped crest was found to be of some advantage at the main weir when spilling occurred, and Mr Seddon added that the semi-circular crest of the sideweir was better kept level and as long as possible so as to take advantage of the low suspended load of the surface water.

126. A variety of alternative sites for the Kial channel along the reach upstream of the sideweir were compared, and it was found that when the channel outfall was relatively near to the sideweir the magnitude of the velocity of the outflow greatly affected the secondary flow at the bend. A low-velocity flow from the Kial tended to strengthen the secondary currents and increased the proportion of material carried over the main weir. On the contrary, a high-velocity flow interacted with the main stream and caused bed scour and transport of the scoured material over the sideweir. This scouring could be reduced by inclining the channel downstream, but the closer the outfall was to the sideweir the greater was the inclination required to minimize scour. Moreover, siting the channel near the sideweir meant that greater stilling was required, owing to the steepness of the Kial channel.

127. The investigation showed that appreciable quantities of deposited material would be scoured from the bed at discharges of 1000 cusecs or more, but they would be diverted by secondary currents away from the sideweir and over the main weir. However, because such high flows would be infrequent, it was necessary to provide for regular sluicing as shown in Fig. 16(c).

128. To the Author's remark on vortex flow in the intake chamber in § 70, Mr Seddon added that flow conditions and the likelihood of air entrainment were investigated in greater detail using a model of the chamber and dropshaft to a larger scale of 1 in 18.

129. In conclusion, Mr Seddon pointed out an inaccuracy in § 71 referring to the Research Station's work on an inclined entrance to the Telom tunnel. No model was used to compare this alternative with a vertical shaft: the work was done theoretically by his colleague, Mr G. H. Lean, who proposed a concrete-lined tunnel entrance with a slope of 1 in 30, meeting the Telom tunnel at a distance of 1563 ft from the intake. The results of the analysis were included in the second report on the Telom investigation.[8]

Mr A. D. Garrod (Binnie & Partners) explained that he had been Resident Engineer on the scheme for the northern half of the civil works.

131. During the construction period there had been four deaths and some other casualties from breathing oxides of nitrogen produced in tunnel blasting. This did not amount to a very high accident rate when it was remembered that 15 miles of tunnel had been driven over a period of four years, involving some 16 000 blasts and 200 000 or 300 000 individual exposures to the blasting fumes.

132. Nevertheless, great concern had been felt by both engineer and employer, and with the active co-operation of the contractor urgent and very extensive enquiries had been made with the object of reducing the danger from fumes. These were being continued in the hope that they might contribute to safety in future schemes.

133. They had begun with a series of measurements of air flows and gas concentrations in the tunnels, assisted by the Department of Chemistry of the Malayan Government. In addition, the effect of water sprays on the soluble gases had been tested with limited success. But the results from just one scheme were not enough, and it was a pity that there was not more widespread measurement, recording and publishing of gas concentrations, particularly if related to the physiological effects noticed after short exposures to high concentrations. Long exposures to low concentrations were rather better documented.

134. In the Cameron Highlands ventilation was by continuous blowing to the face, the longer headings having booster fans distributed along the duct. Curiously, the longest heading—four miles in the Telom tunnel—had produced no serious casualties.

135. The attractions of blowing were good air, free from diesel smoke for the face workers all the time, and good scavenging of the fumes around the muck pile after blasting, allowing a minimal delay before mucking out. On the other hand, the whole of the fumes traversed the whole of the tunnel and quite dangerous concentrations were usually found in the fume plug.

136. This was generally agreed, but it did not suffice to settle the choice between blowing and other systems of ventilation. For a long tunnel of small cross-section suction ventilation was slower, and if diesel traction was used, face workers were subjected to a very thick atmosphere. On the other hand, with electric traction the tunnel was kept free from fumes and if the cross-section was large a slightly longer clearing time after each blast was acceptable in view of the longer cycle time. For a short heading, little time was required for the duct to run clean, after which the flow could be reversed.

137. On the Cameron Highlands tunnels a particularly dangerous situation had sometimes arisen after holing through, when trimming shots—usually carried out at this stage to make final corrections to the tunnel profile—were fired. By their nature, these produced more toxic fumes than normal blasting and coincided with the upsetting of the forced ventilation by natural ventilation while the underground workers were still unfamiliar with the new ventilation routines.

Herr Ernst Dick spoke on behalf of the two German main contractors, Hochtief and Holzmann, involved in the scheme, and expressed appreciation for the invitation to participate in the meeting. The Paper was so comprehensive that no more need be said on the technical points of the scheme. However, there were not only technical problems which had to be solved, for many others were involved. The men employed on the scheme came from many countries in the world, which meant different characters and concepts and different reactions to the facts with which they were confronted. But he truly believed that the work done in Malaya had added to understanding between men, and this was another success of the job.

139. He wished to take the opportunity of thanking the consulting engineers, especially the Authors, for their pleasant co-operation. He expressed his sympathy with the first Chief Resident Engineer and thanked his successor.

Mr A. F. Whillock (Hydraulics Research Station) said that § 61 referred to the fact that a model of the layout had been tested at Wallingford, and he wished to correct any impression that this work had been just a routine examination of a design that had sprung, like Pallas Athene, fully formed from the head of a presiding deity. Exhaustive tests had been conducted on a number of proposals, and these were best described by means of a short film that had been taken towards the end of the work.

141. The spillway and stilling basin, together with a suitable length of the valley, had been modelled to a scale of 1:30. The first part of the film showed the basin fittings which had been found necessary to achieve a satisfactory performance for the final design. A small sill across the width of the basin prevented sweepout at low discharges, and rather large baffle blocks had been required close to the downstream wall to prevent overtopping at maximum discharge. These blocks would have been more effective at a greater distance from the wall, but they would then have interfered with normal low discharges through the basin. They were, however, able to restrain a strong circulation that occurred in the right-hand corner of the basin up to medium discharges.

142. Normal river discharges were passed through the tilting gate positioned at the extreme right of the spillway, and simple plane fillets had been fitted between the right hand wall and the spillway face to direct the flow towards the centre of the basin.

143. Succeeding shots in the film then showed conditions in the basin and the river gorge immediately downstream with the discharge slowly rising from a normal river discharge to a normal flood of 2300 cusecs through only the tilting gate. This was followed by an increasing discharge through the main radial gate up to a catastrophic maximum of 32 000 cusecs (represented by just over 6 cusecs in the model). A point of interest here was that during the early stages of the flood the water level in the gorge was unrepresentative, since the tail gate had to be set for the maximum discharge in the film sequence. Appropriate levels for the model tail gate during test work had been estimated by considering critical flow conditions at various sections in the valley, and the method was described in the annual report of the Director of Hydraulics Research Station for 1957. The position of the standing wave shown in the film at maximum discharge was quite close to that given by calculation; the tail gate being adjusted to give the estimated surface level at the last moulded section of the gorge.

144. Among the designs tested in the model was a very wide basin, the outline of which appeared in the background of some of the film sequences. This had been shown to be very safe, but would have involved more excavation than was considered economic. The basic difficulty lay in the positioning of the right-hand side wall of the basin. In the first design tested the width of the stilling basin had been restricted to the contouring of the gorge, and in consequence the right-hand wall was placed well towards the centre-line of the spillway. The result was that flow from the first radial gate impinged on the oblique portion of the right-hand wall and rode up it in quite a spectacular manner. This difficulty had been overcome by Mr F. Parkinson, who was at the Hydraulics Research Station at the time on an Athlone Fellowship. He proposed a scoop positioned low down on the oblique section of the wall so as to

intercept the flow from the right-hand radial gate bay and turn it over to cross the path of the flow from the other two bays.

145. The last part of the film showed conditions within the small basin with the discharge increasing from normal low flows to a catastrophic maximum, as before. It could be seen that the scoop offered no obstruction to the passage of flow from the side gate, but as the main gates opened the flow from the first gate bay was turned at right angles to its original direction so that it interfered with the other flow and thereby provided considerable energy dissipation. It had been possible, therefore, to avoid the use of very large baffle blocks which would have been required otherwise. It had been necessary, however, to provide overhangs to the basin walls as their height would have had to be raised by some 15 to 20 ft. It should be noted that the level

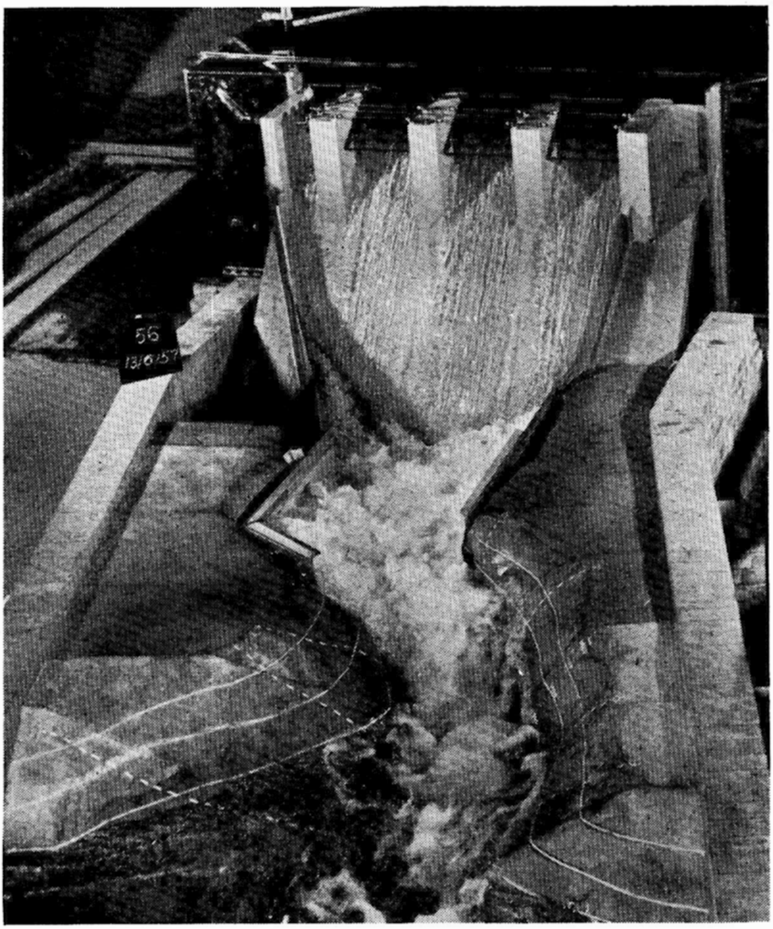

FIG. 23: RINGLET FALLS DAM: 1/30 SCALE MODEL OF SPILLWAY DISCHARGING 32 000 CUSECS INTO RESTRICTED DESIGN OF SPILLING BASIN

in the basin was not that of a true hydraulic jump, but a stable buffer of water had been formed which controlled the outflow from the basin to levels which would occur naturally in the gorge.

146. This restricted design (Fig. 23) had been fully tested and accepted when it was discovered that the sound rockline lay further into the hillside than had been assumed and it was necessary to excavate in any case. Hence, the more orthodox type of basin shown at the beginning of the film had been constructed. In view of the considerably rougher conditions shown in the smaller basin, perhaps it was just as well that this course was adopted.

Mr W. E. Perrott (Cementation Co. Ltd) said the part of the project with which he was most familiar and that which provided for him the opportunity of a very interesting visit to Malaya, was the Colgrouting of the penstocks. It would be recalled from the Paper that the penstocks were 2400 ft long and inclined at an angle of 48° to the horizontal. Their diameters varied from 66 in. at the top to 60 in. at the bottom.

148. As the sections of the steel lining were introduced, the aggregate was placed in the annulus between the lining and the rock. The grouting of the aggregate was carried out through preformed holes in the steel lining, the work beginning at the bottom and working up to the surface.

149. The intention had been to have the work continuous, but certain difficulties at the start of the work due to the use of local materials had meant that tests had had to be carried out and the mix and the procedures altered slightly to allow the work to carry on. Once these amendments had been made, the work had gone through with no trouble at all.

150. Fig. 24 indicated the method used. One of the major questions had been the access and the safety of the personnel in such restricted small-diameter tunnels, with personnel working at different levels. The work had been carried out from an

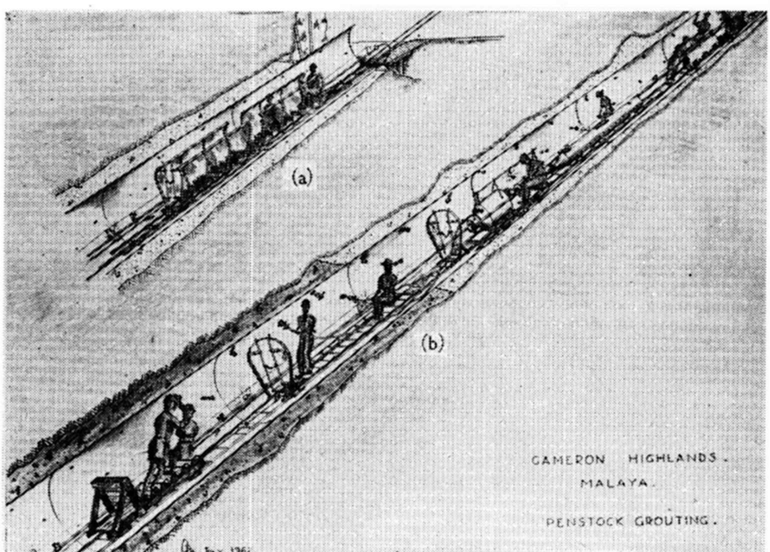

FIG. 24: PENSTOCK GROUTING, SHOWING (a) PERSONNEL TRAIN, AND (b) OPERATIONAL TRAIN

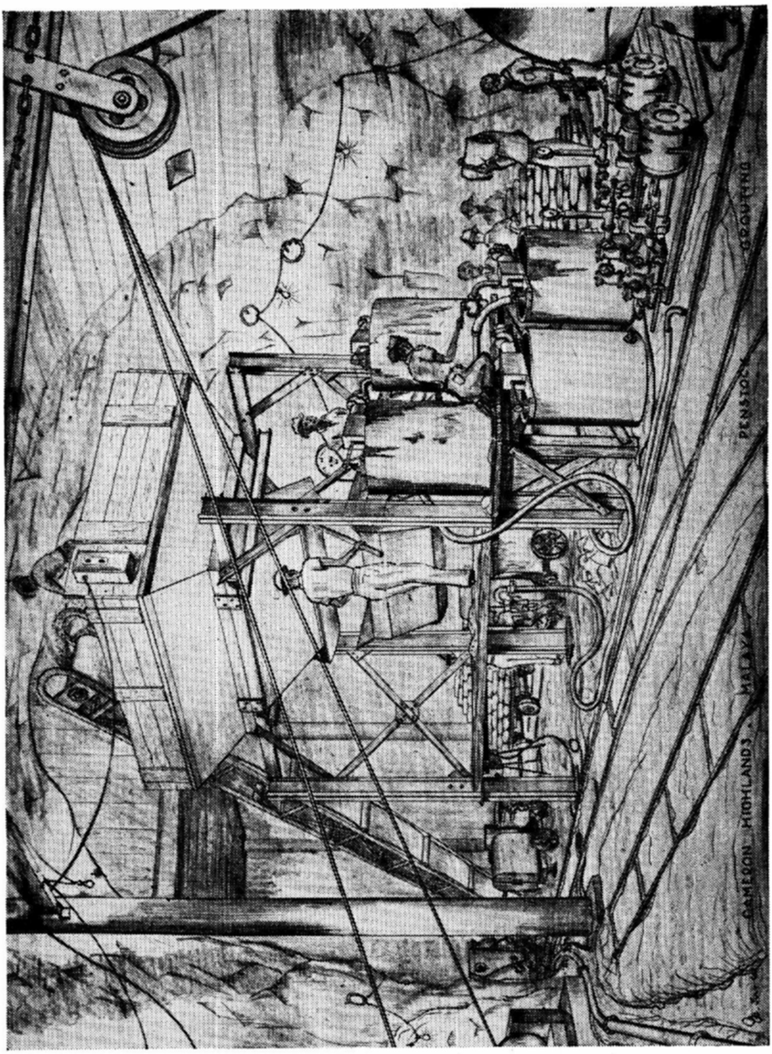

FIG. 25: PENSTOCK GROUTING: MIXING INSTALLATION AT TOP OF SHAFT

operational train running on rails laid on the steel lining. These had been positioned at the bottom of the penstock and pulled up by means of a winch at the top of the shafts at the same rate as the rise of grout in the aggregate. In addition, there had been a personnel car powered by another winch at the top of the shaft, which had brought down and picked up the personnel at the change of shifts.

151. The top working car had consisted of a hooded section on a bogey through which the grout line had been fed in. This had provided a shroud around the 20 ft length of the pipe so that the lower section of pipe could be unscrewed without stopping the pumping of the grout and without spillage of grout. From there the grout had been led into a reservoir which fed the pump mounted on another bogey.

152. Connexion had been by means of flexible pipes to two injection points and the grout had been pumped in through those two. The two points had been used to keep the rate of injection of the grout into the aggregate to acceptable levels.

153. Finally, there had been another car on which men taking out the plug cocks and putting in the permanent plugs had worked.

154. Fig. 25 showed the mixing installation at the top of the shafts. The sand and cement were brought up by rail and loaded by conveyor into the sand hopper from which it was discharged into a weigh batcher which fed the mixers behind the assembly. The cement had been in bags and had been loaded by hand. It had been transferred to the storage reservoirs—four 80-gal tanks—and picked up by the two cementation pumps at the top of the shaft and pumped down the line.

Mr C. D. Crosthwaite (Freeman, Fox & Partners), dealing with the Ringlet Falls storage, said that this was stated to be small and not seasonal, and this was certainly the case, but when one looked at the flow duration diagrams and curves in Fig. 6 one could not help being struck by the extraordinary regularity of the flow. He had never seen such an ideal duration flow curve—47% of the flow was more than the average. He imagined that there had been a very favourable regime and that the Authors had been able very nearly to achieve what was required—a seasonal storage. They could almost cover their demand right throughout the year, for there did not seem to be much difference between wet and dry season in that respect.

156. He put a question to Mr Dickinson about the Habu Station. He could find no mention of the operating head. From Fig. 3, he calculated that it must be about 240 ft net operating head.

157. Apparently the machines in that station had been controlled by Giljets. In Appendix 5 he had seen that the pressure rise on full load rejection was given as 29%. Surely that figure had not been reached. His experience of Giljets was that the pressure rise on full load rejection was much less than that. Was that the figure for which the penstocks had been designed? What rise had been attained on the full load rejection tests?

The following contributions were received in writing:

Mr H. C. V. Woollard (Hydro-Electric Commission, Tasmania) observed that the Authors were to be complimented on their excellent Paper; many features of the works described were of considerable interest to hydro-electric engineers. Among these was the provision of duplicate pressure shafts which, with their associated isolating valves, must have added substantially to the cost of the project. The added expenditure represented, of course, a premium for security, but Mr Woollard wondered whether, perhaps, this provision was not over-cautious, even allowing for the fact that Jor at present represented a major portion of the total installed capacity of the system. The very thorough corrosion-protection described should have a life of twenty years or more; during such a period, if the rate of growth of load indicated in Fig. 4 was continued, the capacity of the system would have been redoubled at least twice over. Under these conditions a planned shut down at Jor twenty years hence, for maintenance of the conduit system, might well be possible without undue operational embarrassment. This was the philosophy which had led the Hydro-Electric Commission, Tasmania, to serve the 300-MW station at Poatina with a single penstock and pressure shaft, although this station currently represented some 35% of the installed capacity of the system.

159. The Authors had mentioned that the result of flat jack tests in the rock in the power station area were inconclusive. This was the initial experience at Poatina; however, with improved techniques and statistical interpretation of the observations, good correlation was obtained between the in-situ tests and the results of photo-elastic studies. At Poatina, which was sited at a depth of 500 ft in tight Permian mudstones, the vertical stress was about twice what would have been expected from the weight of overburden, while the horizontal stress was about twice the vertical. Although the resulting boundary stresses approached the unconfined compressive strength of the rock, it proved possible, by controlled excavation and the use of stress-relieving slots, to support the whole of the machine hall excavation, including the roof, by means of grouted rock bolts and a thin coating of lightly-reinforced pneumatically-applied mortar.

160. The Authors had quoted a figure of 0·45 cu. yd/kW installed. This, of course, was a relatively high ratio and was partly accounted for, no doubt, by the separate excavations for valves and transformers. However, the use of horizontal machines was perhaps also significant in this connexion; the Commission's studies had suggested that more compact layouts were possible with vertical Pelton installations. At Poatina, with vertical two-bearing Peltons operating at 2750-ft head, with surface transformers and with main and isolating valves placed within the main excavation, the volume of excavation amounted to 0·115 cu. yd/kW. This figure included the unloading and assembly bay, and a large underground control building.

161. The Poatina project had been described by Endersbee and Hofto[9] with particular reference to the studies in rock mechanics for the power station. Publication of the paper by D. J. Kluth on the rock mechanics at Jor was awaited with interest. The achievement of further economy in the construction of large underground works obviously depended very much on future developments in this field.

Mr W. G. Lockett (Senior Hydraulic Engineer, Geo. Demers, Ing.P., Montreal) remarked that planning studies such as those referred to in §§ 8 to 13 assumed a peculiar importance when the economic development of emerging countries is considered. He hoped that a paper dealing comprehensively with these studies might be forthcoming in the future.

163. Referring to Fig. 7, the curve of maximum flood flows was an 'envelope' curve, similar to that given in Creoger and Justin's Hydro-electric handbook.[2] If the available records were erratic and/or of different lengths, there would appear to be no reason why the envelope of maximum flows plotted therefrom should obey any law whatever, unless all the peaks happened to be due to the same storm. On the other hand, if the available records were continuous over a significant period of years, the flows for each recording station could be analysed on a probability basis. It would also be feasible to study and make appropriate allowance for the effect of different lengths of record on the estimation of a flood having a given probability. The variation of peak flow with drainage area could then be determined for each of a number of selected probabilities. The result would plot on Fig. 7 as a family of curves.

164. From the table given below Fig. 7 it might be deduced that the length of record prior to 1960 was at least 20 years in the case of five stations, 30 years in the case of six stations, and 63 years in the case of one station. It would be interesting to know whether, following the more recent receipt of these records, an analysis on the lines described above has been carried out, and if so what was the probability of each of the three design floods.

Mr C. G. Cumming (Senior Engineer, Sir William Halcrow & Partners) wrote that, since the power which could be developed from a hydro-electric station was proportional to the product of quantity of water available and the head, it was evident that, for a high-head scheme utilizing a comparatively small quantity of water, the success of the project would depend very largely on the estimation of the long-term average run-off.

166. In the section of the Paper devoted to hydrology it was stated that the average rainfall at Tanah Rata in the centre of the catchment was 103·6 in./a and that correlation of all available data suggested an average run-off to be equal to 4·5 cusecs/s. mile. This represented 59% of the annual fall and by comparison with the run-off from other Malayan catchments would seem high. It would also appear that the output of 354 million kWh/a quoted in § 8 was based on the full utilization of the long-term average run-off of 4·5 cusecs/sq. mile. If these predictions were correct, it would be of interest to know what special circumstances existed for such a high run-off figure to have been adopted in the estimation of output.

The Authors, during their introduction, gave the following additional information. Some interesting figures have been derived for friction coefficients in the 6½-mile-long Telom tunnel, using the approach described by Colebrook.[10] Based on measurements of the actual cross-sections of the unlined tunnel taken at approximately 120-ft spacing throughout its length, Manning's coefficient of friction *n* for rock was calculated as 0·030 using the mean measured diameter and 0·026 using the theoretical diameter to the clearance line. Close agreement had been obtained to this latter figure from site measurements of head and flow which had been made since the scheme was commissioned. After allowing for head losses due to inlet, outlet, bends, lay-bys, and sudden changes of section due to the concrete linings, the value of *n* for the completed tunnel, based on the theoretical diameter to the rock clearance line, appeared to be 0·023. This was the combined surface friction of rock, gunite and concrete in the proportions of length stated in the Paper.

168. Electrical strain gauges were fixed to the outside of the steel lining of one of the Jor high-pressure shafts in two locations along its length. Readings taken during the first filling and emptying of the shaft showed that under head from the reservoir, the lining was taking between 37 and 45% of the water pressure. This confirmed the design assumption that not more than 50% would be taken by the steel and that the rest would be transferred to the concrete surround and the rock.

169. In reply to Mr Hunter's questions about Ceylon the Authors observed that the silting of the Norton reservoir had been bad. Two years ago when the Government had decided to empty it, the reservoir was found to be full of silt up to the invert level of the tunnel intake. For a considerable period prior to that it was probable that the whole of the solids coming into the reservoir had been passing through the turbines. The other reservoir referred to by Mr Hunter had gone into operation three or four years previously, reducing the direct catchment feeding into the Norton reservoir to about ⅛th of its former size and consequently reducing the rate of siltation.

170. There was a provision in the contract, now nearing completion, for dredging the Norton reservoir and a floating dredger could periodically clear out the usable storage and discharge dredgings over the dam.

171. The serious problem of loss of valuable top soil by erosion had been fully appreciated by the Ceylon Government and measures were in hand to minimize soil erosion. The effect of large quantities of silt passing through the turbines had not been sufficiently serious to require the renewal of nozzles or spear points. No doubt this was due to the fact that the material was not all sand. One Pelton bucket had been broken but this probably resulted from material left in the tunnel invert at the time of commissioning rather than to material carried into the tunnel from the reservoir.

172. An attempt had been made in the Cameron Highlands to set up a catchment

authority to control soil erosion. Unless this proved effective, sedimentation of the Ringlet Falls reservoir was inevitable. In the new hydro scheme downstream of the Cameron Highlands, settling tanks to catch the coarser fractions of sand were being constructed at most of the sidestream intakes.

173. Referring to Mr Seddon's remarks about the design of the Telom intake, operating experience so far showed that the predictions of the Hydraulics Research Station about scouring provisions had been correct. There was evidence that considerable amounts of entrained air were being carried into the Telom tunnel and some minor modification may be necessary in the intake chamber.

174. In reply to Mr Crosthwaite's question about the head at the Habu station, the gross head was given as 320 ft in § 7. The design head was 300 ft. The penstocks were designed for a 29% pressure rise, this condition being assumed to occur as a reflected wave after full load acceptance. No figures were yet available for the rise on full load rejection tests.

175. Mr Lockett had asked whether a probability analysis had been made from the records tabulated below Fig. 7. No such analysis had been made. The records were not available at the time the design floods were chosen. Records would in any case be missing for the war years and furthermore would in general be derived from once-daily stick-gauge readings, thereby missing the characteristic afternoon floods, and not from continuous flow recorders.

176. Mr Cummings had questioned the high proportion of run-off to rainfall. This is probably explained by the evaporation losses being lower than in most other parts of Malaya on account of lower temperatures and a greater number of overcast days. The annual rainfall for Tanah Rata was quoted in the Paper as being typical, but not the average, for the area. The rainfall in the northern part of the catchment was somewhat higher, but the period of record was short. Fig. 6 showed that about 95% of the water entering the Ringlet Falls reservoir was utilized at the Jor station.

177. There were three reasons why the turbine valves in the Jor power station had not been located, as was more usual, in the machine hall. The first was that the provision of the cross-over arrangement whereby three sets could be supplied from one shaft was difficult to arrange within the machine hall. To locate this within the span of the main crane would have made the machine hall excessively wide. The second reason was the constructional advantage of having the shot-blasting and grouting operations in the penstocks, and the turbine valve erection, taking place remotely from the erection of machine sets. Thirdly, the machine hall was secure from flooding in the event of a turbine valve failure.

178. In 1961 the General Manager of the Electricity Board in an address to the Joint Group in Malaya of the three Institutions, had forecast the growth of total installed capacity in Malaya to meet the probable demand for the next 30 years. Referring to potential hydro electric sources he had foreseen in 1967 about 138 MW of hydro capacity and in 1975 335 MW, and in 1984 578 MW. Over that period the proportion of hydro capacity in the system would rise from 29% to 44%. Thus the Cameron Highlands scheme was the first in a series of hydro schemes to be built in Malaya. The Authors hoped that the information given in the Paper would be of some help to designers of these future schemes.

References

5. J. R. Rydzewski. Stresses in the head of a buttress dam using photoelastic methods. Symposium on Concrete Dam Models, Lisbon, October 1963.
6. Hydraulics Research Station. 'Cameron Highlands Hydro-electric Scheme, Malaya: Ringlet Falls Dam'. Report on model investigations, July 1957; Appendix, May 1958. The Station, Wallingford.
7. Hydraulics Research Station. 'Cameron Highlands Hydro-electric Scheme; Malaya: Telom Weir'. Report on model investigation. The Station, Wallingford, August 1958.

8. HYDRAULICS RESEARCH STATION. 'Cameron Highlands Hydro-electric Scheme, Malaya: Telom Weir'. Report on hydraulic design of tunnel entrance. The Station, Wallingford, September 1958.
9. L. A. ENDERSBEE *and* E. O. HOFTO. Civil engineering design and studies in rock mechanics for Poatina underground power station, Tasmania. *J. Inst. Engrs, Aust.*, vol. 35, no. 9, September 1963, pp. 187–203.
10. C. F. COLEBROOK. The flow of water in unlined, lined, and partly lined rock tunnels. *Proc. Instn civ. Engrs*, vol. 11, September 1958, pp, 103–132.