# Discussion.

**Mr. H. J. F. Gourley,** in presenting the Paper, showed a number of lantern-slides illustrating the works described.

**Sir Clement Hindley,** Vice-President, in proposing a vote of thanks to the Authors for their Paper, said the present occasion appeared to be unique, as it was, he believed, the first time in the history of The Institution that a Paper had been presented by the President during his term of office. The Paper related to a work of very great magnitude and of outstanding importance in the locality where it had been erected. The work possessed some very unusual and interesting features, particularly the measures which had been taken to prevent progressive percolation. It was recognized that progressive percolation through the concrete could be a most serious danger, and the work done in the present instance, particularly in relation to the cut-off curtain and the diaphragm, showed great ingenuity and a full appreciation of the dangers which had to be met. Although about 6 years elapsed from the time of the beginning of the survey to the time of completion, it was of interest to find that the work itself was carried out in a period of $2\frac{1}{2}$ years, a most remarkable feat under the conditions in which it had to be done. It would be of interest to the members, as it always was in such cases, to know the total cost of the work.

**The President,** in inviting Sir William Peel to take part in the Discussion, said that Sir William was Governor of Hong Kong at the time that the works were in progress.

**Sir William Peel** said the history of the inception of the scheme was better known to Mr. H. T. Creasy, who was Director of Public Works when Sir William went to Hong Kong in 1930, than to himself. The scheme had been under discussion for some time, but some difficulty had been experienced in obtaining the necessary authorization to proceed with the work. When he came home on leave in 1932, however, he got the Colonial Office to cable to Hong Kong to say that the preliminary work might start, and to inform the Engineers at home that they could make their preparations and get on with the work; later in the year, he travelled out with Mr. G. B. G. Hull, the resident engineer, who put the work in hand at once.

He would like to congratulate the Authors and all those concerned on the work that they did in connexion with malaria, which threatened them from the very beginning of their work. At Shing Mun merely to oil all the pools in the depressions formed by the earthworks would not have met the difficulty at all adequately. It was a very bad malaria area, and miles of anti-malaria drains had to be constructed in a big circle around the

Shing Mun dam. There could be no doubt that that saved the situation, because at the beginning the mortality was heavy amongst the Chinese labour; although malaria was never eradicated entirely, the anti-malaria drains, which were well constructed, reduced the sickness and mortality to a minimum.

**Mr. W. T. Halcrow** remarked that the dam consisted of a watertight skin on the upstream face of an embankment which provided the necessary weight to resist the thrust of the water. It thus differed materially from the usual form of embankment dam, where watertightness was obtained by a central core of clay or concrete. The principle governing the design was one to which some attention had been given in recent years, and Mr. Halcrow believed that in America some small dams had been built consisting of a stone bank with a sheet of steel, or an equivalent seal, on the upstream face. Where the estimated life of a dam was short, as in the case of certain mining works, that design was no doubt economical, but such a simple design could not be adopted for the Gorge dam, where an indefinite life was required. It had occurred to him, on looking at the cross section of the Gorge dam, that the thrust-block, which was a very heavy mass of concrete, might have been to some extent, if not entirely, dispensed with had the upstream slope been made flatter. With a stone bank, the chief difficulty was to find a suitable design or material for a flexible watertight face to allow for movement of the supporting bank under the weight of the water. It was possible that the articulated slabs of the Gorge dam, which the Authors had designed with great care, might be adapted in such a case.

Some years ago in Norway a concrete dam, which was leaking badly and was rapidly becoming unsafe, had been repaired by building a diaphragm-wall some 3 or 4 feet in front of the dam and supporting it by struts from the face. The diaphragm had been made watertight, and the dam provided the supporting weight without alteration. Any seepage through the diaphragm wall was drained from the bottom of the space between the diaphragm and the dam. That design could be adopted in the case of a dam to be constructed. Only recently he had had to examine a similar repair scheme for another dam in Norway, which was built of masonry and leaked badly. A watertight facing was to be provided, with drainage, leaving the existing dam untouched. In those cases the diaphragm did not require to be articulated, as the supporting wall would not settle. The principle upon which the design was based was, however, the same in each instance.

Whilst he agreed generally with the remarks about the incorporation of a rich and poor concrete deposited at the same time, which was customary in the construction of concrete dams, he had never come across any cases where visual cracks had been located between the two classes of concrete, but in his own work he had endeavoured as far as possible to reduce to a minimum the thickness of the rich concrete. It was difficult to secure a watertight junction between concrete which had already set and green concrete deposited above it, and he liked the method adopted in the present instance. The introduction of copper strips between the lifts was a positive way of ensuring that there should be no seepage, and he was surprised that it had not been more generally adopted. He had some doubts regarding the placing of concrete in 20-foot lifts. Very strong shuttering was required, and unless girders of great depth and stiffness were used there was bound to be some deflexion as the weight was imposed. There was no certainty that the concrete in the bottom part of the lift had not set to some extent before all the concrete had been deposited, and that might affect the strength or impermeability. With regard to the "Callendrite" sheeting which had been used extensively, he would like to ask the Authors if they considered that it would have an indefinite life, and, if not, whether in the course of a few years it would have fulfilled its purpose and would not be required to function.

The reason given for the adoption of rock-fill instead of earth-fill to support the thrust-block was that the water might find its way into the earth embankment and cause slips. In view of the provision of the drainage-space between the diaphragm-wall and the thrust-block, there would not appear to be much risk of percolating water affecting the supported embankment. However, Chinese labour was cheap and there was no doubt that if the extra cost of stone over earth-fill was small, the stone was much to be preferred.

The sand-wedge was interesting, and its function was explained. He would be a little doubtful about depending upon it for the stability of the upper part of the thrust-block. Whilst precautions had been taken to ensure that the sand would not find its way into the rock-fill by having the face of it set in cement mortar, it was mentioned in the Paper that one of the considerations borne in mind in the design was the possibility of earth-tremors, and it appeared to him that in the event of earth-tremors occurring of sufficient strength to cause substantial fissures in the face there might be risk of sand escaping and taking away the support of the thrust-wall. In his view, the stone backing could be carefully placed behind the thrust-block or consolidated by a heavy roller so as to ensure a solid bearing of the block on the stone.

The description of the movements of the thrust-block was extremely interesting, as it was not usual to find a dam tilting upstream when the water-pressure was applied. The following might be a possible explanation. The rock on which the dam was built contained cracks and joints, some of which were filled with clay or china clay. When the reservoir was full, the floor of the reservoir immediately upstream of the dam was compressed slightly, and so caused an upward tilting of the thrust-block. Movements of structures such as jetties were known to occur when the tide rose and fell, a jetty sinking as the weight of water on the foundation was increased and rising when the tide ebbed.

**Mr. H. T. Creasy** remarked that the island of Hong Kong was studded with reservoirs, those reservoirs being connected with catchwaters that prevented the greater part of the water running from the hills down into the sea, which took place very quickly, the island being a mass of high-peaked hills.

The crisis in regard to water-supply came about in 1929, when the reservoirs were depleted and there was no means of getting water across from the mainland except in water-boats which were requisitioned. The position was such at that time that ships coming to Hong Kong were asked to fill up their tanks, so as to bring Hong Kong water. The total capacity of the reservoirs on the island was between 10,000,000 and 11,000,000 gallons per day, which was really the requirement of the island, so that anything else had to be brought across from the mainland by means of a pipe-line that had been laid to connect with the Kowloon reservoirs, which were then giving 5,000,000 gallons per day. The pipe which was first put across was able to supply to the island 3,000,000 gallons per day. Fortunately, after the arrival of Sir William Peel as Governor the Shing Mun scheme was sanctioned. The pipe referred to had since been duplicated by a 24-inch diameter pipe.

**Mr. J. S. Wilson** observed that in earlier days a dam consisted of a solid mass of concrete, which supplied the necessary weight and had an impervious face, and that all the experiments with regard to stresses in dams had been related to the stresses in such a homogeneous structure. Since then there had been great changes, and the idea of a homogeneous mass had been abandoned; in fact, it was stated in the Paper that the enormous natural granite beds in the vicinity were divided up into comparatively small blocks by fissures. Not long ago some very careful experiments had been carried out in America in an attempt to measure the stresses in a concrete dam, but although great precautions had been taken to obtain accurate figures, no exact results had been obtained. The intention had been to measure the actual strains produced in the concrete by the pressure of the water, but it was found that those strains were rendered invisible by temperature-strains, creep-strains, and so on. In the Gorge dam the various requirements were met individually. The penetration of the water was entirely prevented by the face, which was capable of conforming to all the local movements which might take place. To offer resistance to the face there was the thrust-block, which transmitted the thrust in a uniform manner to the large mass of packed granite. In addition to those provisions, the Authors had had to contemplate the possibility of earthquakes.

The deflexion diagram (*Fig. 10*, p. 196) was very interesting, and he was sorry that the Authors had not given their interpretations of the meaning of the curves. Had the Authors carried out any investigations into the stress–strain relation of the rock-fill?

**Mr. G. M. Binnie** observed that, as stated in the Paper, the diaphragm was poured to a height of 20 feet in one operation. Before shuttering could be designed for such a high lift, it was necessary to carry out a full-scale experiment to determine the pressures likely to be exerted by the concrete during placing, and he showed a lantern-slide illustrating the apparatus used.

Two concrete side walls 21 feet high were built against a vertical wall with a space 2 feet wide between them. The remaining side consisted of planks 2 feet long, set at a batter of 3·4 to 1 for the lower two-thirds and vertically for the upper one-third of the total height, thus corresponding to the face of the diaphragm. The ends of the planks rested on steel bars placed horizontally across knife-edges built into small openings left in the side walls. The concrete was poured into the form thus made in one operation in 3½ hours, giving an average rate of rise of about 6 feet per hour. The pressures against the planks were transferred at the ends on to the steel bars, thus causing the bars to deflect under the load. The pressures exerted by the concrete were deduced from the deflexion of those simply-supported steel bars, the deflexions being measured relative to a second row of rigid bars by means of a micrometer.

The concrete used was a good workable mix containing 600 lb. of cement per cubic yard, with an average slump of 1 inch. Two men were engaged in placing the concrete, one with a spade and the other with an automatic rammer. The results indicated that the pressure against the shuttering at a batter of 3·4 to 1 was equivalent to that of a fluid with a density of 110 lb. per cubic foot, up to a maximum of 330 lb. per square foot at 3 feet head, no increase in pressure being observed above that head. A similar experiment was also carried out for a vertical face 16 feet high in one pouring. The results of the latter experiment indicated that the pressure against vertical shuttering was equivalent to that of a fluid with a density of 124 lb. per cubic foot, up to a maximum of 558 lb. per square foot at 4½ feet head, without any increase in pressure above that head.

The results obtained from those experiments were used as the basis for the design of the steel shuttering, the working stress being 8 tons per square inch. Mr. Binnie showed a model of a steel panel, and said that the panels as finally constructed weighed 1,200 lb. each, seven panels making up the width of 25 feet. The panels were each used about twenty times during the construction period, and were in excellent condition at the end of the job. They showed no signs of fatigue, indicating that the concrete pressures deduced from the experiments were evidently safe assumptions.

In the Paper it was stated that the steel panels were held at the bottom by means of a groove in the step below, and at the top by tie-bars fixed to the thrust-block. They were thus supported with a 20-foot clear span, without any bolts or wires liable to rust and cause leakage going into or through the concrete.

The panels deflected slightly under the load. When the upper ends were released after the concrete had set, the panels sprang away approximately ½ inch at the top, thus automatically stripping themselves from the concrete. As there were no bolts from the concrete projecting through the panels, the panels could then be lifted immediately and placed elsewhere wherever required. Owing to the ease with which the panels could be erected and stripped and the great number of times each panel was used, the cost of shuttering per square yard for the steel panels compared very favourably with the usual wooden shuttering.

One of the principal advantages of the high-lift construction was that it gave only one horizontal joint every 20 feet to be made good against leakages, instead of from four to six joints with the more usual lifts. In spite of the exceptionally high lift poured in one operation, the average rise of temperature of the diaphragm-concrete, containing 690 lb. of cement per cubic yard, was only 38° F., as compared with 53° F. for the concrete containing 600 lb. of cement per cubic yard in the tongue trench. That moderate rise in temperature for so rich a mix could be accounted for by the large surface area exposed for dissipation of the heat generated by the setting concrete. The high lift had also the effect of compressing the semi-liquid mass under its own weight during construction, so that a very dense concrete was obtained, which proved to be absolutely watertight. The following were some of the advantages of the high-lift type of construction: complete absence of steel connexions into or through the concrete capable of rusting and permitting leakage; ease and economy of construction; reduction in the number of horizontal joints in a given height, giving fewer possible paths for leakage; and improved density of the concrete.

**Mr. J. M. B. Stuart** said that in various places in the Paper it was mentioned that the underlying material was granite, but it was not stated definitely that the catchment was on granite. In other parts where granite catchments had been found the water coming off those catchments was soft and had a progressive disintegration-effect upon the concrete in dams. In the Gorge dam, there seemed to be no doubt that there was considerable water-pressure under the concrete in the base of the thrust-block, as evidenced by the leakage into the inspection-gallery, and if the water were soft there might be some danger of deterioration in the concrete at the base of the thrust-block. In connexion with the stability of the dam, the thrust-block was founded on sound rock but it had not been taken in very deeply, and there was no cut-off; there therefore seemed to be no doubt that there would be a certain amount of leakage under the thrust-block. It was not thought necessary to remove the sand and boulders which overlaid the solid rock in the stream-bed from the area where the rock-fill was going to be deposited. The compression of the material in the bed of the gorge underneath the rock-fill was about 4 feet. The rainfall in the locality seemed to be very heavy at times, and the rainfall would certainly percolate through the rock-fill and get down to the foundations of the dam. The water percolating along at the foundations of the dam under the rock-fill might possibly cause further settlement of the rock-fill. The rock-fill exerted a certain amount of passive resistance to the water-pressure, but with further settlement of it there might be some downstream movement of the thrust-block. The sand-wedge was apparently designed to counter that, but would the sand-wedge be active enough to have the desired effect ?

He was doubtful if the provisions made for flood-disposal were sufficient. It was stated on p. 199 that the actual run-off in the past from the catchment had been at the rate of 5 inches per hour, and that the flood-hydrograph showed a peak inflow of 17,400 cusecs. On p. 202 it was stated that the maximum discharging capacity of the bellmouth and siphons amounted to 16,000 cusecs, allowing 3 feet of freeboard, which was equivalent to approximately 5·25 inches per hour. If there had been a run-off of 5 inches in the past, to make provision for 5·25 inches in a work of the kind in question did not seem quite sound, nor did he think that that provision would agree with what was recommended in the Interim Report of the Committee of The Institution on Floods in Relation to Reservoir Practice [1]. The provision made for flood-disposal might be quite sufficient for normal floods, but it seemed to him that it might not be anything like sufficient for the really big flood which occurred once in 50 or 100 years and upset all previous calculations. The flood-discharge system consisted of the bellmouth and the siphons, and they had very little overload capacity ; there was a freeboard of only 3 feet with a discharge of 16,000 cusecs. In a dam of the kind in question it was not possible to allow any overflow to take place, because it would mean the immediate destruction of the dam. The Pineapple Pass dam was referred to in the Paper : it closed up one of the outlets from the catchment. The actual level of that dam did not appear to be given, but it might be possible to construct an emergency spillway for a catastrophic flood so as to avoid any risk to the Gorge dam.

**Mr. F. C. Temple,** referring to the statements in the Paper that one of the considerations on which the design of the dam was based was possible earth-tremors, and that it was seen in Japan that the effect of an earthquake on a solid masonry dam might be serious, said that, in view of those statements, he was surprised that anything so solid as the cut-off wall and thrust-block should have been adopted. It might be of interest to give an illustration of how extraordinarily mobile the earth was during a big earthquake. The Bihar earthquake of 1934 extended over an area roughly 300 miles long and 100 miles wide ; in that area, of every four houses one was destroyed, two were more or less damaged, and one remained intact. Over four hundred bridges were down or unsafe, and nearly every earth embankment had subsided, whilst the sides of the rivers came in and their beds came up. That had produced the most extraordinary effects. In a bridge with two 100-foot spans, the centre well had remained where

[1] Inst. C.E., 1933.

it was, and the two others had moved respectively 6 feet and 8 feet towards the centre, with the result that the girders had pushed the tops of the abutments over. The wells, however, were undamaged and practically vertical, and he had new abutments built on them. Everywhere there was a tendency to level things up. There were not very many reinforced-concrete structures in the area of the earthquake, but those that existed were all undamaged. A reinforced-concrete 50,000-gallon tank on a brick tower of piers and arches 40 feet high was undamaged, although the tower was split by a fissure 2 feet wide and had to come down.

For that sort of country it was obviously best to build the lightest practicable framed structures, insulated as far as possible from ground-tremors by a loose cut-off, of which the ideal pattern would be round balls in a tray. Actually there was a patent extant in New Zealand in which the superstructure did sit on ball bearings, although that form of construction was obviously impossible for a dam. Weight did not matter on so good a rock foundation, so that it was not likely that the Gorge dam would subside. If a big earthquake occurred, with the movement up and down the valley when the reservoir was full, the rock-fill at the back would be shaken down a good deal, and that would let the sand go. The water might sweep right up the valley, leaving half the dam bare. That type of movement had happened in the case of the Ganges, where the water left the south bank, travelled over to the north bank, exposing half the bed of the river, and then came back to the south bank to a height of some 20 feet above its proper level. The water in the dam, having gone up the valley, might come back with a rush and go right over the top into the loosened rock fill. Judging from the behaviour of structures which he saw in Bihar, he imagined that the most suitable form of dam for earthquake country would be a multiple-arch dam of reinforced concrete, and he would like to know why the Authors had not adopted that design.

**Mr. J. R. Davidson** remarked that, in his opinion, the most notable feature of the design was the articulated diaphragm, or watertight face.

He understood that the term " panel ", as used in the Paper, referred to the vertical strip running the whole height above what was called the solid-face concrete ; namely, the whole of the vertical strip 25 feet in width, and not to the 20-foot lifts in which the panels were brought up. If that were so, it would seem that the panels were not attached in any rigid way to the thrust-block, but merely reclined against it, so that the main articulation was therefore on vertical lines between the adjoining panels, with the possibility of slight movement about a horizontal axis between each of the 20-foot lifts. The use of central vertical grooves filled with molten asphalt, and of bitumen sheeting placed on the flat surfaces on each side of each panel, was very interesting ; he had found that form of construction to be suitable for retaining-walls for reservoirs and filter-beds, but the method which had been adopted of forming the groove by means of a pre-cast concrete block was entirely new to him, and was a particularly neat method. How were those pre-cast blocks held in position while the concrete was being placed ?

In the Authors' design, the "Callendrite" sheeting did not appear to enter the diamond-shaped groove. He had found it very advantageous to carry the bitumen sheeting a short distance into the groove, so that when the molten bitumen or asphalt was poured in, it partially melted the bitumen on the sheeting and got a grip on it. It was of great importance that the pouring of the asphalt should not be done until the concrete was thoroughly dry, and the groove should be kept free of water. For that purpose it was very convenient to build in a small horizontal pipe from the bottom of the groove, which acted as a drain, and which could be plugged immediately before the joint was run.

Reference had been made in the discussion to the question of the probable life of the "Callendrite" sheeting and the thin copper strips. He presumed that the "Callendrite" sheeting contained a foundation of some fabric, and he had found that for some curious reason fabric appeared to have the property of very slowly absorbing bitumen or similar substances ; in the present case, where the sheeting between the diaphragm and the buttresses was subject to very heavy pressure, he doubted if the sheeting would have a prolonged life. With regard to the thin copper sheeting, it was well known that in the case of several of the non-ferrous metals, such as copper and lead, with repeated bendings in opposite directions there was a hardening effect which tended to make the metal brittle, and it was then liable to break off. It was quite likely, however, that the movement of the copper in the case in question would be so slight that that effect would not be found.

Another point, also mentioned by Mr. Halcrow, was the placing of a rich mixture of concrete on the water-face of the block of concrete which was in contact with water. It was undoubtedly very valuable in providing an impermeable surface, and it had a much greater resistance to the action of water, but the Paper did not state the thickness of that rich mix. A joint of greased paper was put between the rich mix and the leaner mix. He had quite successfully put a rich facing of concrete on to the bulk of a leaner mix without any ill effect due to the difference in temperature. Mr. Davidson suggested that, since the resistance to water was very important, it would be very useful if the Building Research Station would consider making tests to ascertain what thickness of a rich facing of concrete could be put on to bulk concrete without causing trouble through difference in the rise in temperature.

*** **Mr. J. K. Hunter** was particularly interested in the description of the exploratory work carried out in the vicinity of the dam preparatory to making a final selection of the site. The work was apparently carried

*** This and the succeeding contributions were submitted in writing.—Sec. Inst. C.E.

out by the orthodox methods of opening up trenches and sinking bore-holes, which were tedious and costly operations when a large area had to be covered, and the sound rock lay far below the surface. It appeared that after the site of the dam had been provisionally chosen, further borings disclosed that an extensive zone of decomposed granite covered a part of the site at a depth of 50 feet, and as a result of that discovery it was decided to change the location of the dam. During the past few years the practice of sub-surface exploration by electrical methods had been successfully developed, and had in several instances been used effectively in carrying out preliminary examinations of the sites for proposed engineering works, including dams. Such methods were rapid and appeared to be reasonably reliable; moreover, they could be carried out at a small fraction of the cost entailed by boring. They did not supersede boring operations entirely, but by carrying out a comprehensive preliminary survey the most promising location could be chosen by examination of the rock contours so obtained, and core-borings might then be used to confirm the results of the electrical survey.

A few years ago he had been responsible for examining the site of a dam which it was proposed to locate on a granite formation. Although it was known that the granite was decomposed at the surface, it was hoped to obtain satisfactory foundations at a reasonable depth. Boring operations on the centre-line selected, however, revealed that in places total decomposition had extended to a depth of over 100 feet, and, although circumstances at the time prevented the scheme being proceeded with, it was considered probable that a more favourable site could have been found by altering the location. The work involved in those operations was slow and expensive, and, if the same or a similar site had to be investigated again, he would recommend that before any boring operations were put in hand a sub-surface examination should be attempted by one of the several methods of geophysical exploration which were now available.

**Mr. B. D. Richards** observed that the interesting and novel section adopted by the Authors was stated to have been dictated by considerations of economy and the avoidance of possible cracks, arising from either temperature-stresses or earth-tremors. It would be of interest to know whether or not the various alternatives considered included a reinforced-concrete arch dam, with wide abutments to distribute the pressure, and if so, how that compared in regard to cost. The diaphragm consisted of what might be described as a series of large concrete tiles, resting against, but not attached to, the buttresses; the joints between the tiles, both vertical and horizontal, were staunched with copper strips. The tiles were thus practically held in place only by their weight. In the event of a serious earth-tremor passing up the valley at a time when the reservoir was partly empty, there would appear to be a tendency for a considerable stress to be put on the horizontal copper strips, and even for the tiles to be shaken off. That tendency would be much reduced by giving a flatter batter to the upstream face or by some system of interlocking of the tiles. Presumably, however, earth-tremors of such magnitude were not anticipated.

In the plan (*Fig. 2*, p. 183) two gaps were shown on the western watershed, one of which was closed by the Pineapple Pass dam. Those gaps appeared to be possible sites for open weirs as an alternative to the escape tunnel and siphon-pipes, although the outlet tunnel would still be necessary. It would be of interest to learn whether or not such an alternative would be possible and economical.

He would like to know whether or not in making the model-experiments on the bellmouth overflow, described in detail in another Paper [1], the effect of placing an inverted cone on the vertical axis of the bellmouth had been tried, as a means of checking vortex-action, which was actually effected by placing a baffle across the diameter of the outlet.

**Mr. R. C. S. Walters** was concerned with building dams on granite in Cornwall. Cornish granite consisted broadly of quartz, orthoclase felspar, black biotite mica, and white muscovite mica; it was less acid than the Burrator (Dartmoor) variety. The river valleys were sometimes wide, forming excellent storage-areas, and at other places were almost as narrow as gorges, forming superficially good sites for dams, and apparently resembling the conditions of the Shing Mun, but on a smaller scale.

Although granite was the formation for the whole of the valley, its composition or physical resistance to denudation obviously varied, but the reasons did not seem to be known. Disintegrated granite generally occurred at variable depths, such as at 105 feet below the surface at Sheep's Tor [2], and at 40 feet below the surface at Burrator, the two sites being quite close together. China clay might occur not only at the surface, but beneath a perfectly hard crust of granite, and it was not safe to assume that the granite would get progressively harder with increased depth. The occurrence of such soft patches of disintegrated granite might be due to water, under pressure from below, containing fluorine and boron arising in past ages through veins.

In view of the change of site at the Gorge dam due to the decomposed granite 50 feet below the surface, mentioned on p. 182, the Authors' views as to why cementation was not tried or adopted would be valuable. Some further particulars of the rock used for the aggregate, and whether or not crushed granite from the site was suitable, would be of interest.

**The Authors,** in reply, said Sir Clement Hindley had referred to the time taken in the completion of the scheme, namely 6 years. As was pointed out in the Paper, the improvement of the access road, anti-malarial work, and the construction of camp accommodation, offices, etc., were all

[1] G. M. Binnie, "Model-Experiments on Bellmouth and Siphon-Bellmouth Overflow Spillways." Journal Inst. C.E., vol. 10 (1938–39), p. 65. (November 1938.)

[2] E. Sandeman, "The Burrator Works for the Water-Supply of Plymouth." Minutes of Proceedings Inst. C.E., vol. cxlvi (1900–1901, part IV), p. 2.

in progress while the exploratory investigations were in hand, and later, as the type of dam to be adopted became more definitely settled, the large amount of plant required was ordered and installed, so that by the time the detailed plans were received from England everything was ready for active construction. Sir Clement also raised the question of cost. The cost of the work was not referred to in the Paper because the dollar fluctuated so much as against sterling, and it would have been possibly more misleading than informative to have given any details. When Mr. Gourley was in Hong Kong in 1930 the dollar stood at 1*s*. 3*d*. and it had varied from 11*d*. or 1*s*. up to 3*s*. or 4*s*. although not over so wide a range during the time that the scheme was being carried out. It might, however, be mentioned that the scheme as outlined was estimated to cost 8,000,000 dollars for construction; notwithstanding extra works which had to be carried out at the low gaps, the addition of 300,000 dollars for the siphons and their outlet works as described in the Paper, and the anti-malarial work costing 122,000 dollars, the scheme was carried out within the original estimate. At the rate of exchange prevailing at the time the estimate of 8,000,000 dollars was made, construction was to have cost £500,000. The fact that, notwithstanding the various extras mentioned, the total expenditure was less than the estimate was unquestionably a tribute to the excellent work of the Resident Engineer, Mr. Hull, and his staff.

Sir William Peel had referred to the anti-malarial work. That involved the drainage of almost 1,000 acres round the camp and residential sites, with the construction of 22 miles of permanent concrete drains. By making those drains of a permanent type rather than by relying upon cutting earth ditches, maintenance charges were reduced to a minimum, and ultimate economy was thereby achieved. The expropriated paddy fields which lay within mosquito striking-distance of the camp called for measures more extensive than usually was the case in the tropics, but the 122,000 dollars spent on the work kept the incidence of malaria within reasonable limits, so reasonable that it had not been necessary to pay extra wages to labour as compared with those paid to similar labour in other parts of the Colony. Quite apart from considerations of health and on merely mercenary grounds, it was economy in a malarial district first to tackle the question of swamp drainage and then to keep a small anti-malarial gang under a foreman trained in that work for maintenance and, where necessary, oiling seeps and small pools which construction work brought in its train. The neglect of those precautions in one case known to the Authors caused labour rates eventually to advance by nearly 100 per cent. and led to considerable delay in the completion of the work.

Mr. Halcrow suggested that the thrust-block might have been to some extent, if not entirely, dispensed with had the upstream face been made flatter. It was in some measure a question of economics, for had the upstream face of the rock-fill been made on a flat slope more or less similar to that adopted on the downstream side, the quantity of rock-fill would have been substantially doubled, and the yardage of the rich concrete of the diaphragm would have been almost doubled, for its thickness at corresponding depths would have remained the same. It was with those considerations in mind that the section as described was adopted as the most economical, having regard to the unit costs of the various items involved. There was the further advantage that by having the thrust-block it was possible to arrange for ready access for inspection, etc., of the diaphragm, and it was doubtful if that would have been practicable had the diaphragm rested directly upon the rock-fill, which was bound to settle somewhat, and certainly irregularly. It might be added that the idea of using a diaphragm in the Gorge dam was suggested by the remedial works on the Norwegian dams to which Mr. Halcrow had referred.

Mr. Halcrow was not happy about the setting of the 20-foot lifts of concrete in the diaphragm, and raised a number of points about the shuttering for the work, which had been almost entirely answered by Mr. Geoffrey Binnie's contribution to the Discussion. The fact that the panels had shown themselves to be absolutely impervious and the joints watertight proved that the concrete had set properly, and that all the measures involved in the construction of the diaphragm had been successful.

Mr. Halcrow and Mr. Davidson had referred to the "Callendrite" sheeting. Personally, the Authors saw no reason why that sheeting should not have a very long life in the situations in which it had been employed in the dam. In every case it was between masses of concrete, subjected to fairly heavy pressure, not exposed to light and always kept in a reasonably moist condition; indeed, the circumstances were almost ideal for longevity.

Mr. Halcrow and Mr. Temple had expressed the view that cracking of the rock-fill following an earth-tremor or earthquake would allow the escape of sand and lead to loss of support to the thrust-block by the sand-wedge. It should be at once said that the kind of earth-tremor envisaged by the design was not such as more than to vibrate or jar the structures involved, and certainly not to cause any material displacement. The effect of such movement would be somewhat to consolidate the sand without, however, causing it to cohere, although, in view of its coarse nature, and even if the mortar jointing adjacent to the sand were to crack, no appreciable loss of sand or of support was anticipated. If an earth-tremor of greater violence occurred, such as to cause a noticeable drop in the level of the top of the sand-wedge and also of the rock-fill above, it would be readily detected and without undue difficulty or expense that rock-fill could be removed, the sand "topped-up," and the rock-fill reinstated.

Mr. Halcrow and Mr. Wilson mentioned the records of deflexion. There could be no question of cantilever deflexion below the level 453, for below that level the thrust-block and cut-off wall were securely held by the sides of the gorge, and it was probable that the loading and consequent compression due to the depth of water in the reservoir in part explained the upstream deflexion of that portion of the dam, although it was to be observed that the maximum deflexion occurred about 4 months after the reservoir was full. He understood that in the Boulder dam the conclusion was reached that the load of water on the bed of the valley had caused general compression. The downstream deflexion of the upper part of the dam did follow more closely the rise and fall of the reservoir, although with some lag-effect, and it was of interest to note the decrease of deflexion as the reservoir fell from September 1937 onwards, indicating the elasticity of the structure. In reply to Mr. Wilson, no stress–strain investigation of the rock-fill had been made.

The Authors were much obliged to Mr. Creasy for giving the short history leading up to the carrying out of the scheme. There was no doubt that for many years past Hong Kong had to construct dams in valleys which had poor storage potentialities, and never until the completion of the Shing Mun scheme had there been a material interval of non-construction; notwithstanding that, there were many years in which restrictions had to be imposed.

The Authors thanked Mr. Geoffrey Binnie for his remarks which supplemented the information given in the Paper.

Although the foundations of the dam were in granite, the overlying material in the catchment area was laterite, free from vegetation and giving rise to "flashy" conditions of river-discharge.

Mr. Stuart suggested that the concrete at the base of the thrust-block would be impaired by percolation if the water were soft. The water was moderately soft, but, as pointed out in the Paper, the leakage from the reservoir when full did not exceed 430 gallons per hour. As the water rose at the greased-paper joint between the thrust-block and the richer concrete facing, the head measured between the base of the thrust-block at the deepest part and the drainage gallery could not exceed 100 feet, and as the base of the thrust-block was 80 feet wide, it was not to be expected even at that section that there would be any material seepage below the thrust block, the more so as any weak places in the granite upon which the thrust-block rested were strengthened by grouting. There was no evidence that any measurable quantity of water in excess of that gauged in the gallery gauging-sump had passed downstream of the thrust-block. Mr. Stuart's fears about excessive settlement of the rock-fill on the hypothesis of percolation under the thrust-block were groundless.

With regard to the provision made for floods, possibly Mr. Stuart did not realize—and admittedly it was not made clear in the Paper—that when the Authors stated that the peak rate of run-off was 5 inches per hour its duration was of a few minutes only, and as stated in the Paper that became reduced by the lag effect to 3·7 inches per hour. Those figures were equivalent to the normal maximum flood of the Floods Committee's Report, upon which Committee, incidentally, both the

Authors served, and it was to be noted that according to that Report, and for conditions in the British Isles, the peak rate of run-off from an area of 3,000 acres was 0·87 inch. It was further stated in the Paper that leaving a freeboard of 3 feet the flood-discharge arrangements allowed of a maximum rate of run-off of 5·25 inches per hour, so that if the increased lag effect of the extra 2 feet in the reservoir were taken into account, a flood exceeding the normal by almost 100 per cent. might be safely dealt with. The Authors, therefore, entirely disagreed with Mr. Stuart's criticism, and the question of an emergency spillway at Pineapple Pass did not therefore arise.

Mr. Temple attempted to make their flesh creep by painting a most gloomy picture of what would happen if an earthquake such as he described occurred at Hong Kong. If it did, neither the Gorge dam nor any other dam would be left standing. The Colony was not, so far as was known, likely to suffer an earthquake, although there was the possibility that there might be earth-tremors of moderate degree, and it was with that eventuality in mind that the design was evolved. Mr. Temple's comments were based upon the hypothesis of a major earthquake, so it was not necessary to follow him in speculation as to the possible effects on the component parts of the Gorge dam. The Authors did not know whether Mr. Temple was really serious in suggesting the merits of a multiple arch dam nearly 300 feet high: personally, they would consider it the least suitable type to employ in an earthquake country.

Mr. Davidson referred to the hardening of copper due to repeated bending backwards and forwards. Any bending to which the copper strips in that case might be exposed would be of an extremely slight character, and embrittlement was not anticipated. The thickness of the rich mixture of concrete was as shown in Fig. 3, Plate 1, portions "1" and "2"; it was not a facing, as Mr. Davidson appeared to think, but the whole of the concrete in those portions contained 600 lb. of cement per cubic yard.

In reply to Mr. Hunter, there was no doubt that preliminary subsurface investigations by electrical means were in some cases advantageous, but for important structures they had to be checked by borings, and, in certain formations, by trial pits as well. After reviewing the preliminary work which was carried out before the final site was selected at Shing Mun and its cost in the light of Mr. Hunter's remarks, the Authors did not consider that there would have been any material saving in time or money had geophysical methods been adopted.

The cost of a thin arch dam which necessitated high and heavy abutments had been considered, but its cost was 10 to 15 per cent. more than the adopted design, and apart from that it was not thought as suitable as that design for withstanding earth-tremors.

Whilst Pineapple Pass was not suitable for the discharge of flood water, the use of one of the low gaps was considered as an alternative to the siphons, but the cost was rather more than that of the siphons.

Mr. Richards' question as to whether an inverted cone was tried in the model experiments raised a point of interest; that device was not tried, but when a circular horizontal disk was placed at the water-surface over the model it was found that vortex motion was prevented, due, it was surmised, to the exclusion of air, and that suggested that the inverted cone would perform the same function and in a manner more practicable from a construction point of view, but it would cost more than the curtain wall.

In reply to Mr. Walters, cementation would not have rendered the upper sites suitable or economical, but it was adopted not only to ensure watertightness below the cut-off trench at the Gorge site, but also to strengthen the brown granite upon which the thrust-block was founded. The aggregate used was obtained entirely by quarrying sound granite.

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*** The Correspondence on the foregoing Paper will be published in the Institution Journal for October 1939.—Sec. Inst. C.E.