Discussion.

Mr. Binnie. Mr. W. J. E. Binnie remarked that Mr. Furkert's Paper was of extraordinary interest; it was seldom that Papers presented to The Institution were devoted entirely to remedial measures of structures which had partially failed. To appreciate the present Paper thoroughly, the original description of the works in question should be studied.[1] The following sentences therefrom would give some idea of the geology of the country:—"The treacherous nature of volcanic formations cannot be over-emphasized. No dependence can be placed on the regularity of the depth of the beds even over short distances, nor can there be any certainty of the nature of the bed immediately underlying a deposit of sound rock. Even the upper hard deposits are not to be trusted." The rock on which the dam was founded was apparently very solid and tough, but Mr. Furkert's description on p. 434 of what was found in boring holes for grouting and dowelling was very interesting. There was a certain amount of seepage below the dam which seemed to vary slightly from time to time, and which of course would require very careful watching. With regard to the cause of the great crack which disturbed the works, in view of the description given on p. 421 of the remarkable properties of the rock, he entirely agreed with Professor Hörnell's opinion as to the probable cause of the movement.

Professor Hörnell and the Author had agreed that the obvious remedy was to keep the water out of the rock. The headrace was therefore made watertight with a flexible and impermeable lining, but underneath the lining on the floor and the side a porous layer was introduced, and Figs. 1, Plate 8, showed that, for some reason or other, water was collected on the outer side of the earth bank forming the channel of the headrace and led into the porous material below. It seemed strange that Professor Hörnell first excluded the water from the top by lining the channel and afterwards admitted a certain quantity into the porous bed below the channel. He himself thought that that was asking for trouble, which appeared to have followed in the form of the two further settlements described in the Paper which were due to the settlement of the bottom of the channel owing to the water entering and carrying away the sand

[1] F. W. A. Handman, "The Arapuni (New Zealand) Hydro-Electric Power Development," *Minutes of Proceedings Inst. C.E.*, vol. 228 (1928–29, Part II), p. 230.

Mr. Binnie.

and gravel underneath. He would like to ask what reason there was for admitting that water. The "dowelling" to repair the crack was extremely ingenious. In conclusion, he would like to thank the Author for having given records of the level of and outflow from lake Taupo. It was curious to see from *Fig. 9*, p. 454, how exceptionally regular that outflow was, showing the enormous balancing effect of the lake, which was most valuable for hydro-electric purposes.

Mr. Hellstrom.

Mr. B. M. HELLSTROM said that engineers often learned more from failures than from successful undertakings, and agreed with Mr. Binnie that the engineering profession should be very grateful to Mr. Furkert for his full account of the troubles which had occurred at Arapuni. There were many references in the Paper to Professor Hörnell, who was a colleague of his in Stockholm. When the crack had occurred, the High Commissioner for New Zealand conferred with Sir Frederick Palmer, who came to the conclusion that it was necessary to find an expert on hydro-electric schemes as well as on the question of the fissure. Sir Frederick therefore submitted Professor Hörnell's name, and he was subsequently appointed by the New Zealand Government.

The Paper gave him the impression that the scheme as actually carried out differed in certain respects from the principles laid down in the report by Professor Hörnell and Mr. Werner, and also from what was discussed orally and later amplified in writing. A renewed study of the report and the correspondence confirmed that impression, and he would therefore like to draw attention to certain statements in the Paper. (Professor Hörnell was at present in Russia, so that he had not had the chance of discussing the matter with him.) On p. 422 the Author said: ". . . it was suggested to Professor Hörnell before he left New Zealand that, instead of laying the flexible lining on the country direct, the sides of the channel should be dressed to an even slope where sufficiently solid, and that elsewhere, in order to obtain straight lines, earthen embankments should be made so that there should be a symmetrical channel from end to end. With this idea he agreed." Professor Hörnell's original idea was to employ concrete walls, one reason being that the area of the headrace should not be restricted more than necessary. When the scheme of earth embankments was again referred to him, after he had left New Zealand, he expressed the opinion that that method of construction might be considered reasonably safe if designed and carried out properly, but that it was impossible for him to pass any final judgment from the scanty information received. Towards the end of the paragraph quoted above, the Author said: "He"—Professor Hörnell—"therefore provided that drain-

Mr. Hellstrom. age from the sides, which previously ran down into the headrace, should be carried at intervals under the side banks and under the lining into the porous layers below." The Author also referred to the pipes used in that connection. The following remarks would elucidate the point raised by Mr. Binnie. One of the basic principles in Professor Hörnell's report was that the surface and the ground beneath the headrace should not be deprived of its natural content of moisture, because it was considered that the best method of maintaining the stability of the ridge between the headrace and the gorge was to maintain its moisture-content as it had been during geological ages. That moisture-content, of course, should not be under pressure, and therefore the water in the headrace had to be separated from the ground. It was considered that the natural moisture-content would be better maintained if rainwater could be allowed to run under the lining; that was one of the reasons why the lining was to be laid on a porous layer of stone and gravel, the other being to prevent uplift under the lining. That porous layer had to be suitably connected with the ground outside the headrace, and it was suggested that its upper part should consist of coarse sand and gravel, to avoid any violent inrush of rainwater. That last stipulation was of considerable importance, and that it was not unnecessary was proved by what the Author called the second trouble, to which Mr. Binnie had referred, and which was described on pp. 444–446. "Evidently the heavy stream of water discharging into the porous layer from pipe-drain No. 1 under a head of about 16 feet scoured a cavity by washing the sand and fine gravel into the more open broken stone and spalls." The drainage-pipes were arranged at intervals, as shown on Fig. 3, Plate 8; those pipes, which he presumed were not filled with any porous material but were left open, could evidently, as stated in the Paper, be subjected to a static head of no less than 16 feet. Their entrances, as shown on the cross section, were covered with broken stone and shingle, but he did not think that could be considered as being able to prevent a violent inrush of rainwater. He felt sure that, had details of that design been submitted to Professor Hörnell, he would not have approved of it.

The Author said on p. 424: "It is rather unfortunate that, in his report, Professor Hörnell did not definitely specify the thickness of these concrete slabs"—the slabs for the lining. Actually Professor Hörnell did recommend that the slabs should be 8 inches thick, and that they should be reinforced. The last time he did so was by a letter (which Mr. Hellstrom had read) which reached New Zealand in September, 1931. To judge by photographs in Mr. Hellstrom's possession, the concrete lining had not then been laid.

The Author said that when Professor Hörnell's opinion was received Mr. Hellstrom. it was then too late to make the alteration, but the impression given by the photographs to which he had referred was confirmed by a progress report signed by the Author and dated the 10th November, 1931, in which he stated that the foundations for the slabs were well advanced, but in which there was no mention of the slabs having been laid. It would be noticed from the cross section in *Figs. 2* (p. 423) that the thickness of the concrete slabs on the slope of the embankment was only 3 inches, and personally he could not understand why it was too late to provide the headrace with a thicker lining, even if notice had not been taken of an oral recommendation. He would like to hear the Author's remarks on that point. It was all the more desirable to increase the thickness of the slabs, as that thickness no doubt stood in a certain relation to the velocity of the water, and by the introduction of earthen embankments the area of the headrace had been restricted and the velocity of the water thereby considerably increased. In that connection it should be remembered that the headrace not only carried the water to the turbines, but also the flood-water, which was discharged over a weir at the downstream end of the headrace. The Author described the cracking of the slabs, which made it necessary to put on another layer of 6 inches at the bottom. They were 25 feet square; he would like to ask the Author whether they were reinforced, and if not why not.

With reference to what was called the third trouble, no definite cause was stated, but it appeared to have emanated from the second trouble. It seemed that the inrush of water had scoured beneath the lining outside the area enclosed by the cofferdam built for the remedy of the second trouble, and he thought that as long as the drainage-pipes were open they might still be a source of trouble in the future.

Regarding the cost, the Public Works Department arrived at an estimate of £330,000 for the repair work, excluding that at the falls, but including concrete walls along the headrace. That sum Professor Hörnell found reasonable, but he did not express any definite opinion on the point, owing to lack of knowledge of local conditions and prices. What was said in the Paper—"His estimate of the works, of which no plans had been made when he reported, was between £500,000 and £600,000" was apparently due to some misunderstanding. According to the Paper, the cost of the repair work on the headrace and so on, excluding the falls, amounted to some £300,000, and part of the saving of £30,000 had probably been effected by reducing the thickness of the slabs in the lining. He thought it was open to discussion whether, for an important work such as that in question, it would not have been justifiable to have

Mr. Hellstrom. had some extra factor of safety, which could have been obtained by some further moderate capital outlay.

In conclusion, he would like to compliment the Author and his assistants very highly on the extraordinarily able and efficient manner in which the difficulties had been overcome and the repair work carried out. He need only refer to the description of the grouting in the holes to a depth of 250 feet and the grouting of the headrace under water; he thought that the way in which that work was done required special commendation.

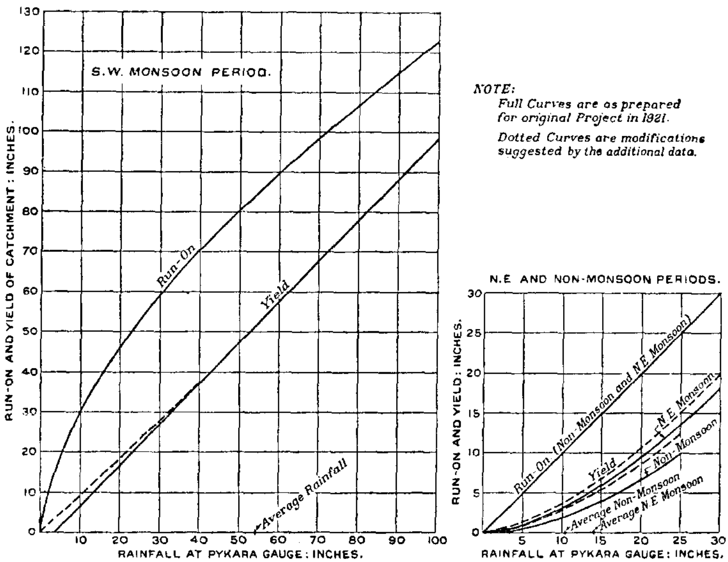
Mr. Richards. Mr. B. D. Richards said that the Paper on the Pykara hydro-electric development was of special interest to him, as he thought he might claim to be the father of the Pykara scheme. The great possibilities of the Nilgiris for the development of water-power had been recognized some years ago. In 1916 the late Mr. R. B. Joyner, C.I.E., the pioneer of Indian water-power, drew attention to the matter in a memorandum addressed to the Government of Madras; while referring generally to the Nilgiris, he had investigated more particularly the Kundah river, the second of the two main rivers which drain the Nilgiri plateau. In the report of the Government of India Hydro-Electric Survey, which was published a few years later, the Pykara site was referred to, but its head was, Mr. Richards believed, put at only some 800 feet. In 1920 Mr. Richards made an investigation of the Nilgiris, and found that the Pykara site was more favourable than the Kundah for the development of power. A head of over 4,000 feet could be brought under command in two stages of about 3,000 and 1,000 feet respectively, the 3,000 feet being obtained by the difference in level between the Nilgiris and the Mysore plateau, and the further 1,000 feet by leading the tail-water from the first power-house through two short canals and a river to the Mysore Ditch, where the Moyar river, an extension of the Pykara, flowed in a great ravine some 1,100 feet below the surrounding plains. The Government of Madras granted him survey rights, and with the co-operation of Mr. Alfred Dickinson a syndicate was formed to promote the undertaking. He returned to India in 1921, made a detailed preliminary project for the Pykara scheme, and negotiated with the Government of Madras a concession on behalf of the syndicate. At that time another company had held a licence for the development of the Kundah scheme and for the supply of power to the towns on the Nilgiris and to Coimbatore and its district. It was proposed to transmit power from the Pykara scheme to the port of Calicut on the Malabar coast, about 64 miles away, for use in industries to be established there. In 1924 the syndicate received a proposal for the return of the concession to the Government of Madras. The Kundah scheme had not materialized, and the Government were considering a policy of electrical development as a State enterprise. The possibility of being able to organize the Pykara scheme, and more particularly the industries to utilize the power, within the time-limit of the concession seemed somewhat unpromising, and the syndicate decided to accept the proposal. An agreement was entered into for the return of the concession, under which copies of his report, plans, and estimates were to be handed to the Government. As the Author had mentioned, the Government's ultimate scheme followed closely the layout of the original project, but certain modifications had been introduced to facilitate the more gradual development of the scheme by stages, so as to suit the market for the power. Two additional small streams, the Sandynalla and the Glen Morgan, had been impounded, and the utilization of the regulated water of those, supplemented by the unregulated water of the Pykara, formed the first stage of the scheme. The Government also proposed to construct a series of four storage-reservoirs, in place of the single storage-reservoir which it had been intended to form by the construction of a dam across the Pykara river in the gorge above the Gudalur road bridge, if trial-pits had proved the site to be suitable for a dam of the height required. Mr. Richards.

The Author had referred to the somewhat meagre hydrological data available, and had given in some detail the method by which the estimate of the available water had been arrived at. It might be of interest to compare the Author's methods and results with those of the original project of 1921. At that time there were on the Nilgiri plateau ten Government rain-gauges, with records of from 36 to 50 years, and also six private rain-gauges on tea-estates, with records of much shorter periods. The only river-gaugings were a few which had been made by the Government for the purpose of ascertaining the minimum flow of the Pykara. It was therefore necessary to estimate the available water from the rainfall, though it was intended to supplement the estimate later by river-flow measurements. None of the rain-gauges lay in the actual catchment, but one of them, the Pykara gauge, was on the lower edge of it, and that was adopted as the master gauge. The year was divided into three periods: south-west monsoon, north-east monsoon, and non-monsoon. A study of the rainfall data showed that for the north-east monsoon and non-monsoon periods the rainfall of the Pykara gauge might be taken as representing the average rainfall over the catchment without introducing any serious error; for the south-west monsoon period, however, the average rainfall over the catchment was very much higher than that at the Pykara gauge. A series of years, 1915 to 1920, was taken when the maximum number of gauges was available; isohyetal charts of the rainfall over the catchment during

Mr. Richards. the south-west monsoon period were made for each year, and the average rainfall estimated. From that a curve was deduced showing the run-on of the Pykara catchment in relation to the rainfall of the Pykara gauge for the south-west monsoon period. This showed that in a normal monsoon the catchment received 159 per cent. of the rainfall of the Pykara gauge. In a heavier monsoon that percentage decreased; in a lighter monsoon it increased. No yield-factors or rainfall-loss data were available for the determination of the yield; he therefore assumed yield-factors for the average rainfall of each month, taking into account the amount and distribution of the rainfall and also the size and nature of the catchment. Those factors ranged from 0 to 70 per cent., and from them he deduced for the average rainfall of each period yield-factors of the catchment of 60 per cent., 40 per cent., and 20 per cent. for the south-west, north-east and non-monsoon periods respectively; for the maximum rainfall they were increased to 80, 60 and 40 per cent., and for the minimum rainfall reduced to 30, 20 and 10 per cent. Applying those factors to the run-on curves, yield-curves were deduced showing the yield of the catchment in each period in relation to the rainfall of the Pykara gauge.

For the purpose of comparing his results with those of the Author, he had applied to these various curves of run-on and yield the rainfall of the Pykara gauge for a period extended to 1927. He obtained an average run-on on the catchment of 68 to 152 inches, with a mean of 108 inches, whereas the Author's figures were 60 to 181 inches, with a mean of 109 inches. They were therefore in close agreement as to the mean rainfall over the catchment, but the Author had a rather wider range of extremes. Mr. Richards had estimated the annual yield of the catchment to range from 33 per cent. to 73 per cent., with a mean of 55 per cent., but he now thought his yield-factors were too low, and indeed they had been intended as a conservative estimate. In the light of the additional data for adjacent catchments which the Author had given, he would be inclined to increase his yield-factors for the north-east and non-monsoon periods, and also for the minimum rainfall of the south-west monsoon period. Making the adjustments he had in mind, the yield-factor would range from 40 per cent. to 75 per cent., with a mean of 58 per cent., which seemed a reasonable expectation from such a catchment. His original and adjusted results were shown graphically in *Figs. 1*. The Author's figures were 63 per cent. to 81 per cent. with a mean of 75 per cent., and were therefore much higher than his own, and also more uniform. The Author arrived at those results by an interesting method based on the rainfall-loss as deduced from the records of two adjacent catchments, but that method would seem to imply two assumptions which might introduce considerable error. Those assumptions were, firstly, that the rainfall-loss was directly proportional to the rainfall, and, secondly, that it was independent of the size and steepness of the catchment. The rainfall-loss was undoubtedly not a constant, but he thought it was probably influenced more by the distribution than by the amount of the rainfall. The flatter and larger a catchment, the greater was likely to be the time-lag, and therefore the greater the rainfall-loss. He thought it was generally accepted that the yield of a catchment increased with the rainfall, and that it was greater the smaller and steeper the catch- Mr. Richards.

Figs. 1.



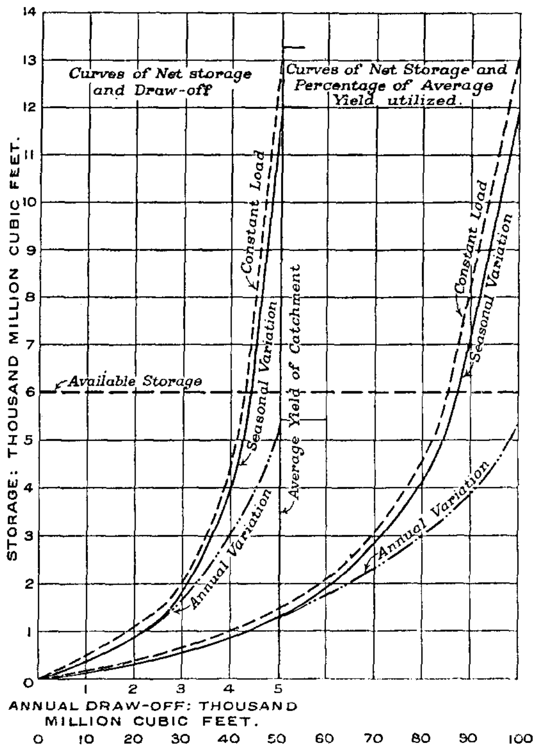
ment. The Thalipuzha catchment, which the Author took as representing the Pykara catchment in a year of maximum rainfall, was a small and very steep catchment with a very heavy concentrated rainfall, of which 88 per cent. fell in the south-west monsoon. A very high yield-factor would be expected from such a catchment, and the figure of 84 per cent. given as the average for 4 years was not surprising. The Pykara catchment, on the other hand, was 6 times as large as the Thalipuzha and was less steep. It derived about the same proportion of its rainfall from the south-west monsoon, but its maximum rainfall was only some 60 per cent. of the average rainfall of Thalipuzha. It would therefore appear that a considerably

Mr. Richards. smaller yield-factor would be obtained from Pykara than from Thalipuzha, and personally he thought that the figure of 81 per cent. found by the Author was relatively much too high. The Sandynalla catchment, which the Author took as representing the conditions of the Pykara catchment in a year of minimum rainfall, was about half the area of Pykara. It had a 3-year average of 46 inches of rainfall, which was about three-quarters of that of Pykara in a minimum year. Its yield-factor was found to be 55 per cent., and from that the Author deduced for Pykara a yield-factor of 63 per cent., which seemed to be unduly high for a year when the south-west monsoon had almost entirely failed. The more uniform the yield of the catchment, the less, of course, would be the storage-regulation required. The Government proposal gradually to build up the storage by the construction of a series of reservoirs would enable the final storage to be adjusted when more positive data for the yield had been obtained. The Author had allowed for an evaporation and absorption loss of 5 feet from the storage lakes, having obtained records of 4½ feet. It was not clear where that measurement of 4½ feet had been made—perhaps the Author would give that information—but for the storage lakes with their large area and depth he would suggest that a smaller loss might be found. For the single large reservoir which he had proposed he had assumed a loss of 3 feet.

In the original project, the proposed utilization of the power called for a cheap and continuous supply. It was therefore desirable to determine whether any substantial increase of power-output could be obtained by the introduction of a seasonal or annual variation in the load. The alternatives considered were: (1) a constant load; (2) a load with a seasonal variation, the load in the wetter half of the year being taken as 40 per cent. greater than the load in the drier half; (3) a load with an annual variation based on the yield of the previous year, with a proviso that the constant annual load should not be less than 60 per cent. of the plant capacity. The results of those investigations were shown in *Fig. 2*. A seasonal variation gave an increase in power-output of 3 per cent. only. The annual variation gave an increase of 17 per cent., accompanied at the same time by a slight reduction in the storage required. With that annual variation, the annual load would vary from 60 to 100 per cent. of the plant capacity, with a mean of 78 per cent. The idea would therefore have been well worth considering subject to the conditions of the market permitting it, although it would of course have involved an increase in the capacity of the plant, pipe-line, and canal.

He had always regarded the Pykara site as one of the most favourable which he had investigated. The exceptionally high head, the heavy, well-distributed rainfall, the very capacious forebay site, the opportunities for storage and the possibilities of developing the scheme gradually by stages were all peculiarly favourable. He would like to conclude by offering his congratulations to the Author and his colleagues on the successful completion of the first stage of a very interesting power-scheme. Mr. Richards.

Fig. 2.



Dr. W. L. Lowe-Brown, referring to the Paper by Mr. Furkert, observed that the Author deserved sincere thanks for giving such valuable particulars of the troubles experienced and of the properties of the volcanic rock. The description of the absorbent nature of that rock and of the way in which it behaved under pressure and shock would be of the greatest assistance to anyone who had to deal with similar material. The Paper showed clearly how a site which appeared almost ideal had proved in many respects to be most untrustworthy. There was apparently an ideal site for a dam, an Dr. Lowe-Brown.

Dr. Lowe-Brown.

excellent site for a power-house, a ready-made headrace and a ready-made overflow-channel. It was true that there was a fall of 120 feet at the end of the overflow-channel, but no trouble had been expected there and no protection had been provided. A false sense of security had been given by the way in which the columnar vitric tuff had behaved in ordinary construction—it was quite a satisfactory material for concrete, and it weathered very well and hardened under the atmosphere. It had three characteristics, however, which made it behave quite differently from any ordinary rock: (1) its prismatic formation, with vertical lines of cleavage; (2) its porosity (it could absorb up to 50 per cent. of its volume of water); (3) its tremendous compressibility, which was its most extraordinary characteristic. Its modulus of elasticity was given by the Author as 300,000 lbs. per square inch, about one-twentieth of that of ordinary granite. Its density was not stated, but in the Paper by Mr. Handman [1] that of the pumiceous breccia was given as only 120 to 125 lbs. per cubic foot, about that of a rather poor brick.

Stress had been laid in the Paper and in the discussion so far on the crack which had occurred, but the first sign of trouble had appeared at the falls. The face of the falls, which was initially more than 1,000 feet from the spillway, appeared to be safe, but all the time the pool at the bottom was being scoured out, and then suddenly the face gave way and receded 100 feet. It had been hoped that a state of equilibrium had been reached, but further falls had taken place at intervals, and the retrocession appeared to become more rapid. Drastic measures had therefore been required to stop it. Looking backwards, of course, was always the easiest way to do a job, but it did now seem almost inevitable that that damage should have occurred. He believed that if anyone who had had any experience of large bodies of water impinging on rock had been among the Author's advisers he would have suggested some protective work before the channel had been opened. The protective works which the Author afterwards built had been criticized as extravagant, but he did not agree at all with that criticism. To withstand the tremendous forces of large volumes of falling water it was hardly possible to make the work too strong, and he felt that any attempt to whittle down the thickness of the concrete would have involved a grave risk of serious damage in time of flood.

The headrace-protection had already been discussed fairly fully. He would only say that the system adopted seemed unnecessarily complicated, and that complication seemed to have led to damage. If the Author would say what he would do if he had to deal with the

[1] Minutes of Proceedings Inst. C.E., vol. 228 (1928-29, Part II), p. 249.

same problem again his experience might be of the greatest value. As the crack was considered to have been caused by the old channel which formed the headrace being filled with water, the Author must have been anxious regarding the possibility of damage due to the forming of a large lake behind the dam, where the water-level had been raised by 130 feet or more. It would seem that that had far greater disruptive powers than those of the water in the headrace. No doubt the dam would act as a strut to keep the two sides of the valley from coming together as the ground swelled due to the raising of the water-level, but he thought the Author must have been unfeignedly thankful that the curvature of the dam had a radius of 120 feet. The ground round the dam seemed to have been well reinforced, and the grouting must have given it very great support; but, although the steel rods used for dowelling were placed somewhat closer together than they were over the crack, he thought that they should have been closer still. He could not see that a 1-inch steel rod could afford much effective support to 200 square feet or thereabouts of crack; he thought considerably more steel than that would be required, and he noticed that in repairing the concrete of the penstocks the rods used for what the Author called "stitching" had been placed only 8 inches apart. The Author described the very careful precautions which were taken when the lake was filled a second time, but apparently no automatic alarm system had been placed on the drains from the dam, although on the drainage-tunnels under the crack it would appear that automatic alarms had been installed to give warning of any excessive leakage. His own impression was that the dam was a point of greater potential danger than the crack. Dr. Lowe-Brown.

Mr. JAMES WILLIAMSON added his thanks to the Authors for their exceptionally interesting Papers. Mr. Furkert's Paper was a very frank and full description of costly remedial works. The cost might seem excessive in relation to the value of the subject, but that might be because it was not readily realized just how valuable the site was for the generation of power. When the complete scheme was in operation, generating 120,000 kilowatts with eight machines, the possible output would be of the order of 600 to 700 million units a year. He had made some rough calculations from the figures of cost given in Mr. Handman's Paper and the additional costs given in the present Paper; so far as the first stage was concerned, where plant of only 45,000 kilowatts was installed, and assuming that the load was an ordinary mixed domestic and industrial load amounting to about 3,000 hours of use a year, the cost, even including all that had been done in remedial works, would not exceed about 0·2*d.* per unit. When the whole installation was in operation, the cost Mr. Williamson.

Mr. Williamson.

should be reduced to about 0·07*d.* per unit. The especial value of the river in question arose largely from the natural regulation of the very large lake at the head of the catchment. The topographical conditions were extraordinarily similar to those at the Trollhättan plant on the Gota river in Sweden, where lake Väner, which he thought was still larger in proportion to its catchment-area than lake Taupo, had a very large regulating effect on the river. The water was impounded by a relatively small dam, carried along a shelf and then down through very short pipe-lines in a tunnel to the power-house, which he thought was a larger installation than was contemplated at Arapuni. In each case the topographical conditions favoured economical development, but at Arapuni the geological conditions were far more difficult. Judging from the costs given, in spite of high wages in New Zealand the work seemed to have been carried out very economically indeed; in particular, the very deep drilling, vertically, on the incline and on the horizontal, seemed to have been done as economically as could be hoped for.

Lake Taupo was at a height of 1,180 feet above sea-level, and from that point the river was regulated to a very large extent. It might therefore be possible to develop power at other places, and the flow and regulation were such that it would pay handsomely, with reasonably favourable site-conditions, to develop in stages of as little as 40 or 30 feet at a time. If only half the power were developed, the possible output would approach 2,000,000,000 units a year. In connection with the discharge from the lake, *Fig. 9*, p. 454 (prepared originally by Mr. Lush, with whom he had had the pleasure of discussing the matter) correlated the run-off from a big catchment-area and from a big lake with the sun-spot periods. At first sight it might be thought that there should be no connection at all, but in other cases also a certain connection had been found between the sun-spot periods and the general rainfall. That was particularly the case with lake Victoria Nyanza in Africa, where the relationship was similar to that found at lake Taupo, namely that at periods of solar maximum—the greatest sun-spot periods—there was in general, taken over a series of three or four years, high rainfall, and at periods of solar minimum there was low rainfall. The solar periods recurred at intervals of about 11 years; that was probably connected with the fact that it was generally considered that to get a reliable figure for average rainfall it was necessary to consider a period of the order of 33 or 35 years.

The Paper by Mr. Platts on the Pykara hydro-electric development also gave the information and costs in a very full and frank manner. The work was an example of a high-head development such as was not likely to be found in Great Britain but which might however, be possible in many parts of the Empire. In connection with run-off, a rough comparison might be made with British conditions. Mr. Richards had made some observations on the relation of the loss of rainfall to the quantity of rainfall. In the west of Scotland the lower rainfall was on the lower and flatter ground, and the high rainfall was in the hills on the steep ground. On the lower, flatter ground, where there was more vegetation and a slower run-off, there was a larger loss than on the upland areas where the rainfall was higher. On ground with 35 to 40 inches of rainfall there might be a loss of 12 to 14 inches, whereas in the case of the higher ground, with 80 to 100 inches of rainfall, the loss might only be 7 to 11 inches. In country such as the West Highlands, therefore, the yield-relationship was very much more favourable in the high-rainfall areas than in the low-rainfall areas. The Author's Table on p. 463 gave the variations from the mean of the Pykara rainfall-gauge for a 50-year period, in which the driest year's rainfall was given as 60 per cent. and the wettest as 165 per cent. of the mean. In Table IV (p. 462) the estimated total run-off was given; the lowest figure was 38·2 inches, in 1918, which was 46 per cent. of the average run-off (80 inches, calculated from a summation of the whole of the figures). On the other hand, the highest run-off was that for 1882, 146·8 inches, which was 180 per cent. of the average run-off. If those estimates were reasonably reliable, as no doubt they were, the variation of run-off was considerably worse than the variation of rainfall, which was what would be expected, and was far more than was obtained in Great Britain. Mr. Williamson.

Taking the costs of the various items given in the Paper, it appeared that the work had been carried out fairly economically, so far as prices in rupees could be compared with prices in English money; taking Rs.1,000 as £75 the costs seemed reasonable; but from p. 494 it would be found that those costs were not inclusive, and that there were considerable incidental costs to be added. Those incidental items, together with the sum of Rs.569,000 given for "general headquarters' charges and expenses," amounted to approximately 40 per cent. of the construction costs, and it was possible that even that was not the whole story, because there was no mention of cost of land, compensation, and interest during construction. Allowing something for those two items, the cost of the development of the scheme appeared to be about £40 per kilowatt. It was unlikely that any future extensions of the development would be carried out at anything below that figure, as they would have to carry the cost of very large storage-reservoirs. He noted from the Table on p. 471 that the scheme for complete development con-

Mr. Williamson.

templated storage of about 3,684 million cubic feet, and from *Fig. 2* (p. 507) that Mr. Richards based his calculations on a storage of 6,000 million cubic feet. He imagined that the cost of providing storage of either of those amounts on rivers subject to such extraordinarily high floods would be considerable.

*** The replies by Mr. Furkert and Mr. Platts will be found at pp. 524 and 532 respectively.—SEC. INST. C.E.
