Discussion.

Mr. J. WOLFE BARRY, C.B., President, said the members would recognize in the work, the description of which they had listened to with so much interest, one of very great importance, which had been carried out under many difficulties, not only from the undertaking itself, but from the inaccessibility of its site. They could scarcely realize in England how much the large works in India had added to them in anxiety and trouble by the difficulties of the climate and by the shortness of the seasons during which the operations had to be carried out. They must all recognize in the works described in the Paper the great care in the calculations, the tenacity of purpose, the resourcefulness of those employed, and the devotion which the staff must have shown in carrying out the undertaking under such difficulties. They would all congratulate the Author on the successful completion of his great enterprise, and also the staff, whose services he had acknowledged in terms so graceful and fitting. He begged to propose a hearty vote of thanks to the Author for his interesting Paper. Mr. Wolfe Barry.

Lieutenant-General Sir RICHARD SANKEY, R.E., remarked that while he had held the position of Chief Engineer and Secretary in the Public Works Department to the Madras Government, between 1878 and 1883, it had been generally assumed that the Periyar scheme should be carried out as an earthen dam of gigantic dimensions, 200 feet in height. To European engineers this would necessarily seem preposterous, as it certainly did to the Author and himself. It had, therefore, been decided that the principle of the work should be that of the latest section adopted by the French engineers; and the dam ultimately took the form which had been carried out in all its details with such remarkable energy and success, that it had been recognized in every direction as one of the greatest works of its kind in the century. The work certainly merited great consideration, since throughout Southern India the country was, and always had been, threatened with famine. In the central and southern portions of the peninsula dependence had from time immemorial been placed to a great extent upon rain-fed tanks—a system of irrigation followed by the natives with wonderful success and energy. In the province to which he had been at one time attached (Mysore), there were thirty-seven thousand of those reservoirs, the largest of which had a surface of 14 square miles. In the Madras Presidency there were about Sir Richard Sankey.

Sir Richard Sankey. forty-two thousand. Such a vast system, or anything comparable to it, did not exist in any other part of the world. Nearly all the rivers and tributaries were, almost from their sources to a certain point, stopped by a succession of earthen banks. One such series in Mysore had no fewer than twelve hundred inter-dependent tanks. The natives had carried out the whole system, but in times of continued drought, particularly when dry seasons followed each other, the country was left with little if any assistance from water, depending entirely upon the tanks, which, being rain-fed, often dried up and failed. That had actually been the case in 1877–8, when there had been a probably more severe, though more localized, famine than the present one. When the engineers first went to India, one of the first duties devolving upon them was to systematize the plan of utilizing all the lower reaches forming the deltaic portions of the different rivers as they debouched on the eastern coast, so as to have the means of using for irrigation the perennial water of the different streams having their origin in the Western Ghats. That carried out by the Author was probably the last in succession of these great works along the eastern coast. Differing materially in design from the deltaic works to the north, it still would have the effect of affording a perennial supply which would be uninfluenced by anything affecting the general country in times of drought, and of insuring that the whole tract should have the means of irrigation. The great triumph of this work consequently was that it dealt directly and satisfactorily with the question of famine. The actual area that had the means of irrigation throughout India was generally calculated at about 30,000,000 acres. Of that amount 7,900,000 acres were due to works carried out by the Indian Government, at a cost of about 33 millions sterling, each work in all the great Presidencies having been originated with a view to counteraction of famine. There was hardly a single work, whether the great Ganges Canal, the Sutlej Canal, or the great deltaic works in Madras, that had not been called forth by that cause. In regard to the Madras Presidency, of the 5,000,000 acres under irrigation, nearly one half had been created by State money appropriated with that object. There were the great delta of works of the Godavery, Kistna, Pennair, Tanjore, and lastly that described in the Paper. The works to which he had referred, were due originally to the genius, courage and skill of Sir Arthur Cotton; and the one under discussion had been carried out by the Author in an equally admirable manner. In regard to the expense, he found the dam had cost £175,000, to which must be added £47,000 for what might be called headworks, the cutting and discharge tunnel, etc. The contents of the lake above the sill level of the outlet were about 13,000 million cubic feet. He gathered from the Paper that the reservoir would fill two or three times a year, so that a total of about 30,000 million cubic feet of water would be intercepted. Accepting the first figure, he found that the cost of the dam would be about 3*d.* per 1,000 cubic feet stored. Adding the cost of the cutting, etc., this amount would be increased to something less than 4*d.*, but, assuming 30,000 million cubic feet to be actually intercepted, the cost would not be much greater than $1\frac{1}{2}$*d.* per 1,000 cubic feet stored. No doubt the Author would be able to give figures showing the cost in similar circumstances elsewhere in relation to the storage. Respecting the great Furens dam, he had not sufficient information on this point, but that of "la Terrasse," which cost £170,000, was calculated to intercept 150,000,000 cubic feet only for a height of 147 feet. The great dam at Lake Fife, near Poona, in Bombay, 97 feet high, cost nearly the same as the Periyar dam. The whole work cost about £625,000, including head and distributing works. In that case the area was about $5\frac{3}{4}$ miles as against 12 miles of water spread over the Periyar dam. In regard to the conditions under which the work under discussion had been carried out, the Author had stated that there were practically five months only during which it could proceed, and this in broken periods. Fevers prevalent in that part of the country and along the west coast of India generally formed a serious obstacle to engineering work. In regard to one work which he had commenced at Mysore, an enormous amount of a then well-known fever specific called "Warburgh's drops" had to be procured in order to counteract the fever. Arrangements had also on another occasion to be made for taking the coolies by carts to and from the works daily. He quite agreed as to the desirability of having a removable shutter, or similar means, at the discharge outlet, to uphold, when required, a higher level of water. Sir Richard Sankey.

Mr. George Farren was glad to see upon the walls of the Institution the representation of a rational dam (*Fig. 2*, p. 143). He had heard it said in that room that such dams were not reliable; but he had carefully examined the one described in the Paper, and had found it very nearly what a scientific dam should be. He had on a previous occasion directed attention to the Chartrain dam, and had compared it with a theoretical one.[1] It was Mr. Farren.

[1] Minutes of Proceedings Inst. C.E., vol. cxxvi. pp. 95–98.

Mr. Farren. satisfactory to find that a dam of that character had been made by an English engineer, and he believed it was the only one that could be called a rational dam in the whole of the British Empire.

Mr. Hill. Mr. E. P. HILL appreciated the magnitude of the difficulties that had been overcome in the execution of the works, and could divine no reason for the prohibition to use a discharge tunnel, unless it were a supposed difficulty in closing at that depth after the dam was finished. In Great Britain the first step in the construction of a reservoir was the discharge tunnel; he therefore asked why in this case that course had been prohibited? The jets of water found spurting up in the foundation before the dam was built, were, he supposed, under the pressure of the water behind the temporary dams. Their height was between 2 feet and 6 feet, under a pressure of about 26 feet. The fissures had no doubt been plugged successfully; but he wondered whether, when the reservoir was filled, and they were under a pressure six or seven times as great as that under which they were plugged, the plugging would be quite effectual; and even whether other fissures under that pressure might not have shown themselves. In the case of the Thirlmere dam, all the fissures that could be found had been cut out, in order that there might be no water-pressure under the base of the dam when the reservoir was filled. Apparently in the present case this had not been thought necessary. He asked what was the specific gravity of the dam, the normal temperature at which it had been constructed, and the range of temperature to which it was now exposed?

Mr. Vernon-Harcourt. Mr. L. F. VERNON-HARCOURT agreed that the form of the Periyar dam was very like that of the Furens dam, which might be called a rational section, except that in the latter a continuous curve formed the outer face, making the width of the dam increase more rapidly towards the base; whereas in the Periyar dam there were two straight lines at an angle, in place of the curve, giving apparently the same kind of section as the Furens dam, though slightly narrower at the base for a similar height. The exact section, however, adopted for a reservoir dam of a definite height, depended upon the maximum pressure to which it was considered the masonry or concrete might safely be subjected; for if a greater pressure than the maximum in the Furens dam, of about 6 tons per square foot, was admissible, then the section could be given a proportionately smaller width. The great water-pressure on these high dams was liable to cause leakage through them, unless the masonry was very compact or the inner face was coated with some impervious materials. No information appeared to have been given

Mr. Vernon-Harcourt.

in the Paper with regard to the watertightness of the dam. Even more interesting, however, than the question of the dam, was that of supplying water for the crops at certain seasons to places deficient in rainfall. In India the nature of the country was extremely arid in the dry season, showing how very important it was to study the meteorology of each district, and to preserve all the water from whatever perennial streams might be available to bring it on to the land. As he had seen in 1896 at Calcutta, the meteorological observations were numerous in Bengal and were recorded in a series of diagrams in a very perfect manner. The variation in the amount of rainfall from year to year was remarkable. In the case of the basin of the Bhagirathi, which he had had incidentally to investigate, in 1895, the rainfall over that limited area was 38 inches in the year, according to the return in Calcutta —taking the average, and probably quite as little or less in 1896; whereas sometimes in that same district it increased to 64 inches or 65 inches. Famines appeared to occur in India mainly after two successive seasons of small rainfall, as in 1877 and at the present time; and irrigation works from perennial rivers offered the best means of mitigating such calamities. There were also much greater variations of rainfall in India according to the locality. In some places the rainfall might not be more than 2 inches or 3 inches, as at the hill station of Leh, while at Cherra Poonjee in Assam, for instance, the average was about 474 inches in a year, which he believed was the highest recorded rainfall in the world. He had no knowledge of Southern India, but it was with great interest that he had learnt from the Paper that, owing to the rainfall being greater on the west coast that on the east, it had been possible to bring some of the excess of the Travancore rainfall on the western side of the ridge of hills into the Madura district on the eastern side, where there was a great deficiency. The Paper was of great interest, especially in connection with the difficulties that had occurred, and the way in which they had been overcome, as well as the fine dam that had been constructed to store up the rainfall, and the tunnel made to convey it through the dividing ridge into the eastern river basin. It was obvious that such works could not be carried out without knowledge of the meteorology of the district. He had been much interested in observing the limited times during which the work could be carried out. In respect of its floods, the River Periyar differed from the rivers of North Eastern India, where the Ganges rose fairly continuously at the head of its delta, beginning slowly about May, and reaching its maximum in September, and then gradually falling. In the Periyar basin there appeared to be

Mr. Vernon-Harcourt. a cessation of floods generally in September and October, and then a recurrence of them; but evidently complete freedom from floods in the interval, in the autumn, could not be relied upon in that rainy district, near the head of the basin. It was necessary to study carefully the meteorology of the district to obtain a knowledge of what work could be done for irrigation, and the periods at which it could be carried out. The two things clearly went together, and the way in which the work had been carried out reflected great credit upon all concerned in it.

Mr. Symons. Mr. G. J. SYMONS suggested the desirability of an index-map to show the positions of the places described in the Paper. With regard to the subject of rainfall, he had the highest appreciation of the magnificent way in which the meteorology of India[1] was being worked. The subject of compensation had not been referred to by the Author. If a stream in England from one watershed had been led through the hills and discharged into another, the original owners would have something to say about it. He was surprised to find the Madura district described as "one of scanty rainfall." The average rainfall in the Madura district was 28 inches, the driest station having an average of 18 inches, and the wettest of about 37 inches, Madura itself having about 33 inches. It certainly was not dry, compared with Kurrachee and portions of North Western India. On a previous occasion[2] Mr. T. Sopwith, Jun., had given interesting details of the temperature of the face of the Mont Cenis tunnel after it had been left a considerable time, so that the effect of blasting and the like had passed away. The results of observations of a similar kind made in regard to the tunnel described in the Paper would be interesting. It appeared that owing to climatic conditions the work was generally suspended three or four months, so that any effect of drilling or blasting, which would have heated the rock, would have had ample time to pass away before the renewal of the work. The general scheme appeared to be an illustration of the great advantage to India of English rule.

Mr. Deacon. Mr. G. F. DEACON observed that the Author had adopted a form of dam which was no doubt perfectly satisfactory and stable if well constructed, as he had no reason to doubt it was; but it behoved engineers to take note of any matters which might appear even on the surface to be otherwise than the best possible practice. He thought the great difference which was apparent from *Fig.* 2,

---

[1] Indian Meteorological Memoirs, Calcutta, 1876, &c.

[2] Minutes of Proceedings Inst. C.E., vol. xxxvi., p. 4.

Mr. Deacon. p. 143, between the rubble and the concrete, did not exist in practice. It might be that the moduluses of elasticity of the two were much less different than would appear when they were placed in juxtaposition with such different shading as that shown in the *Fig.* He did, however, think that the construction of straight-faced walls on the inner face of a dam, against which concrete was subsequently to be placed, was a mistake. There was undoubtedly sheering stress over those long, deep surfaces, and it was certainly desirable to avoid change of structure at planes along which such stress occurred. The next point that struck him as singular was the abandonment of the cutting to the rock on the saddle at the left flank, and the continuation of the dam by means of earthwork not carried down to the rock. The fierce light that shone upon the engineer in England would probably make so bold a course impossible without the risk of serious criticism; but, all things considered, he had no doubt that it was a right thing to do, and it had turned out successfully. He did not, however, understand why this little dam was half of masonry and half of earthwork, with a straight joint down the centre. No doubt the two were properly tied together, but he should be glad to hear why the earth dam was not carried across the full length of the little valley. In test-blocks subjected to compression the depth in relation to the breadth and width was a very important matter. He therefore asked what was the thickness of the test-blocks of concrete which had given such excellent results? To secure uniformity of practice it was desirable to use cubes or cylinders of depth equal to the diameter. If the 80 tons per square foot mentioned at p. 157 as the ultimate strength of blocks, six months old, was obtained from cubes representing the concrete exactly as it was used in the dam, the result was very satisfactory, and was a further justification of the opinion he had often stated and practised—that, except where running water could not be avoided before the lime had set sufficiently to resist it, good hydraulic lime, or, what was in effect the same thing, rich lime and pozzuolana, might, if properly manipulated, be used instead of Portland cement with great advantage and economy.

Mr. Hall. Mr. W. H. Hall observed that the escape-way or waste-way was simply a cutting through rock without any weir or structure upon it. The top of the dam was intended to be 11 feet above the bottom of the escape-weir, and the full flood-water was expected to rise 9 feet of that height. With regard to the areas given for full water at the level of the bottom of the weir, and the 9 feet

N 2

Mr. Hall. increased depth, the storage capacity produced there of 2,716·5 million cubic feet[1] (compared with 6,815 million cubic feet which the reservoir stored *from the level of the outlet-cutting up to the* level of the overflow weir) was nearly 50 per cent. of the effective storage. A structure was thus provided which would really retain nearly 50 per cent. more than the effective storage and lose it again. It had occurred to him whether lowering the cutting by taking out more rock to construct the dam, for the rock for its construction had to be hauled a long distance, and providing a movable dam in the cutting, would not have been cheaper, and at the same time have admitted of lowering the main dam between 4 feet and 6 feet. It appeared that the dam was 4 feet or 6 feet higher than was necessary to provide for storage. A movable dam in the escape-way would have held the water up to within, say, two-thirds of the depth of the 9-foot prism which was now to be wasted. In the United States Geological Survey—which had carried out a few years ago an extensive investigation as to the storage of water in the United States—four hundred reservoir sites had been surveyed. Plans for the dams were made for most of them—standard plans for different kinds of dam—and applied for the study of the storage of water in different classes of sites. He had had the honour of acting as Supervising Engineer on that branch of the survey. The advantage of providing a movable weir or dam in the escape-way to reduce the height of the dam when necessary was always observed. The amount of storage-space estimated to be necessary was 7,000 million cubic feet; but the storage-space actually available between the sill of the outlet and that of the overflow was 6,815 million cubic feet. It was also stated that the intention had been to provide a minimum constant flow of 500 cubic feet per second;[2] and the width of the overflow cutting was 21 feet. He estimated that to produce that flow of 500 cubic feet per second the depth in the cutting would have to be nearly 6 feet, and possibly more, according to the roughness of the sides. He considered that the 3 feet of depth necessary at the reservoir to produce the minimum amount of outflow, was not available for the irrigation purpose, for, in drawing down the water, as soon as the 3 feet of depth was reached the minimum flow was not obtained, and consequently that minimum depth must be omitted

[1] For the expression of such volumes of water the unit "acre-foot" was employed in America. It denoted the volume of water covering an area of 1 acre to a depth of 1 foot.

[2] The velocity of 1 cubic foot per second was in America designated the "second-foot."

from the available or efficient capacity of the reservoir. He estimated that 3 feet of depth to give about 500 million cubic feet, so that only 6,315 cubic feet remained. He did not see in the Paper any mention of loss by evaporation, which assuredly must be great. In America a minimum loss was estimated of 2 feet in a season between the time the reservoir filled and when the water had to be used, and from that up to 4 feet. He considered 3 feet would not be an over-estimate in the case in question. Taking 3 feet as the amount and applying it to the mean of the full-water and the low-water areas—the loss would be 664 million cubic feet. The total was thus diminished to 5,650½ million cubic feet, or about 20 per cent. less than was said to be required. He also observed that the cutting had no gradient for the first 3,000 feet, beyond which it was 1 in 320. To produce in the upper end of the cutting a flow which the lower end would take, there must be an equivalent hydraulic gradient. If that were applied, a little more than 9 feet was taken off the available prism in order to get the water to flow through, so that the amount was reduced by 1,568 million cubic feet, leaving only 4,082 million cubic feet. In order to produce the minimum flow of 500 million cubic feet a second, as soon as the water arrived at that level, the minimum flow would be reduced, else there must be a greater water-way in the upper 3,000 feet of the escape. It seemed, from the figures given, there must be a deficiency of storage below the 7,000 million cubic feet, which were said to be necessary, of as much as 2,000 million cubic feet, or nearly one-third. It would be exceedingly interesting to know why that was. The decision of the professional advisers of the Government for India not to allow the tunnels round the end of the dam, to carry the water away during construction, would in America be considered a very curious ruling. If there were a tunnel round the end of the dam it would be a great convenience when it was desirable to empty the reservoir altogether; in America such provision was always made. It would also have immensely diminished the cost of construction. The point mentioned by Mr. Deacon of the apparent lack of unity between the rubble-construction and the concrete, had also struck him. The back of the front wall appeared to be quite smooth and well worked like the front. In that case there could not be any junction between the two materials; and should there be a leak at any point—especially from a very slight motion due to the difference of temperature, or to the varying pressures at different times—so as to start the smallest rupture between the types of construction, Mr. Hall.

Mr. Hall. there might be a leak through the front wall, there would be hydrostatic pressure, which, in the course of time, might be harmful. He might call attention to the Croton dam,[1] one of the old dams of the New York water-supply, which had been built of concrete with a kind of ashlar facing. The greatest pains had been taken in the construction of that dam to bring the ashlar work and concrete together. Never more than one layer of ashlar was applied before the concrete was brought up; there were alternate layers, with mortar let in to make a good bond; and, as in laying bricks, they were all lapped close together. If the rubble portion had been omitted, and all of the subsidiary dam had been made of earth, the latter would have a better junction with the bed-rock at the right-hand side of the saddle than it could possibly have at the end of the dam to which it was joined. At present, the earth abutted apparently against the vertical wall of masonry; he had known of several failures from that cause. In one case the earthwork embankment or dam had been placed against a nearly perpendicular face of basalt rock, and during one season it was not filled with water. Notwithstanding that it was built in the most careful manner, and was rammed in as much as possible, the earth shrank away from the basalt, and pebbles and gravel-stones could be inserted in the joint before the end of the season. When the water had been let in again, it broke through, and in that way a catastrophe had been prevented.

Mr. Binnie. Mr. ALEX. R. BINNIE thought the Paper described a work carried out under very peculiar difficulties, which few could experience who had not had to work under the tropical conditions described. These rendered it almost impossible to proceed for several months in the year owing to the unhealthiness of the climate; and at other times, owing to the floods, it was impossible to carry on any engineering work, so that only a very small portion of the year in each season was available for active operations. The difficulties of the site were sufficient to discourage any engineer from undertaking a work of that description, and they were added to by the peculiar dictum of the Government in India. He knew what that Government was; it issued its fiats, but did not give its reasons. In the present case, as in many others, the mystery was inscrutable why so very peculiar a handicap was placed upon the engineers who had to construct the work. The work, however, had been completed, and it would carry with it to all time the impress of that peculiar, and, in his opinion, erroneous, judgment.

---

[1] Transactions of the American Society of Civil Engineers, vol. iii. p. 337.

What was to happen should it ever become necessary to empty the reservoir he did not know, short of blasting a tunnel, which ought to have been constructed in the first instance. He could not, however, help thinking the Paper was deficient in many important points. Dealing, as it did, with so important a subject as the irrigation of a district like that of Madura, which was historically dry—the drought from which it always suffered having been, by means of the works described, brought within the compass of engineering skill to overcome—it was almost a pity that the Paper did not describe how it was done. The water must come from somewhere. Where? What was the drainage area? What was the rainfall on that area? What was the average flow of the river? and what was the minimum flow? The difficulties arising from the floods had been carefully pointed out by the Author, but the whole design depended on the sources from which water was obtained. To attempt to criticize the storage provided by the dam, was futile without knowing the amount of water available to place behind that storage, the perennial stream which came down the river, and how much of it could be depended upon in the driest seasons. The case was unique, even in India, in which an engineer had to deal with a perennial stream subject to such great vicissitudes of flood and drought. It would be interesting to have a record of all the great facts on which the work was based. Mr. Binnie.

Mr. F. J. Waring noticed that the sill of the watershed cutting was 113 feet above datum, whereas the bottom of the dam was at the datum level; there were therefore 113 feet of the depth of the reservoir unavailable for irrigation. It was also stated that the contents between these levels amounted to 6,484 million cubic feet, or nearly one half of the total contents impounded. It appeared therefore somewhat strange that the dam had been built so far down the stream. If the site of the dam were chosen higher up the stream, where its bed was at the level of the watershed cutting, the height of the dam would naturally have been much smaller, and it would have been a much less difficult work to execute; no doubt there was a sufficient reason for the present site of the dam, but it was not disclosed in the Paper, and he trusted the Author would give information on the point. From the second Paper, he observed that the ground on which the cutting was made was nearly level, therefore to have lowered the tunnel 113 feet would have vastly increased the work. At a place in Ceylon, near Pattipola on the Haputal Railway, the Cingalese had carried out a similar work upon a small scale, and had diverted Mr. Waring.

Mr. Waring. a stream which flowed into the district of Dimbula, where the wet season was in June and July in the south-west monsoon, to Uva, where the wet season was in October and November in the north-east monsoon, so that the Uva paddy fields below the stream derived the benefit of both monsoons. The ground above the tunnel through the watershed was in this case only about 40 feet in height; the tunnel itself was 120 feet long. It was unlined and passed through compact and hard earth. Although the tunnel was so short it had been excavated by two or three shafts or else the crown had fallen in at two or three places. He had been unable to ascertain when this work had been executed; but the spoil banks were covered with trees of the same kind as the adjacent forest, showing that they must have been deposited a great many years ago.

Mr. Chatterton. Mr. A. CHATTERTON believed the area under irrigation was about 100,000 acres in the Madura district, so that the total capital cost did not amount to more than £5 per acre. With so large a work, in which the dam itself contained 6,000,000 cubic feet of masonry, costing Rs.3,000,000, or roughly $7\frac{1}{2}d.$ per cubic foot, the low cost, under the difficult circumstances described in the Paper, was largely due to the excellent arrangements at the outset for carrying on the work, and the exhaustive and complete surveys made nearly thirty years ago. Such projects in India generally required a long time to mature, and the same individual seldom began the preliminary investigation and carried the whole work to its conclusion. It was no doubt due to the circumstance, that throughout the whole project there had been one mind guiding and controlling, that it had been carried out at such a comparatively small expense. The action of the Government of India in regard to diverting the water through tunnels round the flanks of the dam, appeared all the more curious since about the same time in the Bombay Presidency a dam had been constructed at Bhatgarh for supplying the Nira canal in which the technical advisers of the Government had allowed a totally different course to be pursued. Particulars of it had been given in the discussion on "Impounding Reservoirs"[1] which took place about three years ago. The dam was 103 feet high, and therefore, although it was not so large as that under discussion, it was a considerable masonry work. In its construction not only were fifteen sluices, each 8 feet high and 4 feet wide,

[1] Minutes of Proceedings Inst. C.E., vol. cxv. pp. 159 and 166.

Mr. Chatterton.

permanently provided for the discharge of the water during the flood season, but permission had been given to make a tunnel (the height of which was not stated, but the width was 6 feet) through the dam solely for the purpose of obtaining water for washing sand. If some such course had been pursued in connection with the Periyar dam, the difficulties connected with its construction, especially in the earlier stages, would have been greatly lessened. The diversion of the Periyar River had afforded a source of water-power which, in all but magnitude, was probably unequalled in the world; apparently 60,000 HP. could be developed without difficulty. The question of the successful utilization of the power seemed to depend upon finding means for using it. If the water-power was to be used as a source of revenue, and an amount equal to the returns from the irrigation were to be levied as a charge for it, it was evident that about £35,000 a year would have to be paid for the 60,000 HP. available. Under ordinary circumstances in England, to obtain 60,000 HP. for £35,000 a year would be a good bargain, but it was doubtful whether the water-power in such a locality as the outlet from the Periyar Tunnel, and subject to such a heavy first charge, would be of great value. The question of utilizing water-power had been discussed in Madras during the last few years, and it had been regarded as a possible means of developing the great mineral wealth in the Presidency. It seemed probable that the water-power of the Periyar project might be conveniently used for metallurgical purposes. It was doubtful, at any rate, for a long time to come, whether the development of electrical power at the foot of the ghat, and its transmission to the town of Trichinopoly and possibly Madras, could be carried out. Indian towns were generally comparatively poor, and scarcely likely to be able to afford expensive electrical works. Although electric lighting was possibly a great advantage, the people were not able to pay for it, even if it could be supplied at the rates which might be obtained with a cheap supply of power. In the immediate future, therefore, the only possible prospect of utilizing that large amount of power was its employment for metallurgical purposes. A large amount of power could thus be absorbed in a comparatively limited space, and he believed the Government of India were carrying out investigations as to the natural resources of the districts round Periyar, with the view of ascertaining whether there was material which could be worked by electro-metallurgical methods. If any such scheme were carried out, a charge of Rs.10 or Rs.12 per HP. per annum would

Mr. Chatterton. probably be a serious expense to be incurred by what must be regarded as a pioneer undertaking, and for that reason he thought it was hardly likely that, for some time to come, any considerable revenue would be derived from the Periyar project by the utilization of the water-power at present available.

Professor Unwin. Professor W. C. UNWIN regarded the work described in the Paper as an achievement in which the difficulties were not only of an engineering character, but of a kind to test the pertinacity and endurance of the engineer, and his moral courage. He wished to offer a protest against the suggestion to call 1 cubic foot per second a "second-foot." In a number of cases a unit which was the product of two simpler quantities was employed, and in those cases a hyphenated name was adopted. The product of feet and pounds was called a foot-pound, and the product of degrees and pounds was called a pound-degree, and so on. But in England a little respect was still paid to some conventions; and he did not quite see why feet divided by seconds should be called a "second-foot." The first important point about the Author's work was the composite character of the dam. The second point to which he might refer was the question whether, in a narrow V-shaped valley like that of the Periyar, it would not have been better to build the dam with a curved plan. He did not say that method was certainly better, but he thought it was exactly the case in which a curved plan would have been considered. With regard to the possibility of utilizing the great water-power which poured down on the Madras side of the hills, if there were only some use to which to apply it, great value would be added to the work. It could be developed with less difficulty than in many other places. The fact that no storage or regulation was wanted had been referred to by the Author. There were cases in which water-power had been used and a large expenditure incurred, especially in storage, which had to be constructed in order to make the supply constant and to be worth utilizing. Those, however, were cases where there was a poor water-power in the neighbourhood of a great population, and where the value of the power was so great that the expenditure on storage-works was justifiable. It was an exaggeration to say there was no other water-power so good in the world. He had had to survey one source of power in America with a view of utilizing 250,000 HP., where certainly the difficulties of utilization were even less than at the Periyar. He imagined also, that there were, if they were looked for, many other such positions, and it was not necessary to travel as far as the hills at Periyar to find sources of water-power

Professor Unwin.

which could be utilized very cheaply indeed. He believed they were being utilized to greater extent than English engineers were generally aware of, and the reason why they were not more utilized was the extraordinary expensiveness of the electrical engineer. The moment distant transmission became necessary and the electrical engineer came on the ground, the price of the power increased considerably. At Niagara the price at which the power could be sold had had to be carefully investigated when arrangements were being made to supply the City of Buffalo, 20 miles distant. It had been offered to supply the power undeveloped—that was, to yield the water-rights, the use of the head-races and tunnels, the expensive hydraulic part of the work, for a charge of $10 per HP. per annum, the HP. being supplied twenty-four hours in the day. Further, it would be supplied developed and delivered from the turbine shaft at $13, reckoning that the hydraulic machinery that would be necessary would add to the price $3 per HP. per annum; and it was offered at Niagara, in the shape of electricity at 2,000 volts, at a price of $18 or $20. Contracts had been made for $20, and, in case of Buffalo taking a large supply, $18. He did not know the charge to be made at Buffalo, but the Company had absolutely resisted being tied down to any price at Buffalo, or to supply there, except in open competition with steam power, which cost, with well arranged and economical plants, $60 per HP. per annum for a twenty-four day. The increase was due to the cost of transmission.

Colonel Pennycuick.

Colonel PENNYCUICK, in reply, thanked the members for the kind way in which his Paper had been received. He believed the temperature fluctuated between 50° and 90° F.; the normal was probably between 75° and 80°. The specific gravity of the masonry was about 2·30, or 145 lbs. per cubic foot. Judging from the amounts of material used, the weight of the masonry was not much greater than that of the concrete. The concrete was well rammed, and contained a small quantity of mortar carefully mixed, and he did not think the masonry weighed more than 150 lbs. per cubic foot. Reference had been made to the small fissures in the bed of the river when it was laid bare. They could hardly be called fissures, for they were little more than capillary tubes, tiny spurts rising to 2 feet or 3 feet. To have cut them out or to have provided for them by drains would have been of doubtful utility, and would have certainly taken a great deal more time than they were worth. They were choked without the slightest difficulty, and he had no doubt that long ago they had been filled by the earth and material brought

Colonel Pennycuick. into them by the force of the water. At all events they had not given trouble, and he did not anticipate any. He had not the slightest idea what were the reasons that had led the Government of India to prohibit the tunnel through the dam. One object among others for using a tunnel was to provide for the possibility of having to unwater the lake hereafter. That, however, was prohibited, and he had to do the best he could without it. There was no Congress to go to in India. Its Government was a very autocratic body. "*Sic volo, sic jubeo,*" was all it had to say. Choice had to be made between dropping the work altogether and carrying it out as the Government insisted, and he thought most engineers who took a pride in their profession would say that those who had the work in hand were right in doing the best they could to carry it through. He entirely agreed as to the importance of meteorological observations; not only the nature of the work itself, but the whole of the proceedings from beginning to end, were absolutely ruled by such considerations. For some years before the work had begun, and during the whole time of its continuance, careful observations of the rainfall had been made twice daily at two stations in the area of the lake, and those records had been carefully consulted before any steps were taken for raising the water-level, or closing a vent, or any other purpose. He did not think accurate records of the temperature had been taken in the tunnel; it was not considered a matter of great interest, the conditions of the tunnel being totally different from those of the Alpine tunnels. The greatest distance from the sill of the tunnel to the surface of the ground above was never more than about 200 feet, and the variation of temperature could hardly be a matter of importance. It had been observed that the slope of the rear face of the dam consisted of a series of straight lines in place of the curve which a theoretical section would give. It was only in the lower part of the dam that the theoretical section would be an unbroken curve. In the upper part the points to be chiefly considered were the absence of tension in the front face of the masonry and resistance to over-turning and sliding. A simple triangular section was really the theoretical one for these three considerations, and the curve, due to the resistance to crushing, only came into play in the lower part of the dam. With a dam of that height, for the first 40 feet or 50 feet it was a very flat curve, and practically the section, as given, *Fig. 2*, p. 143, did not differ anywhere by a foot from the theoretical section. The amount of compensation had been fixed at Rs.40,000 a year for the right to take the water, and the negotiations leading to it had been long and troublesome.

Colonel Pennycuick.

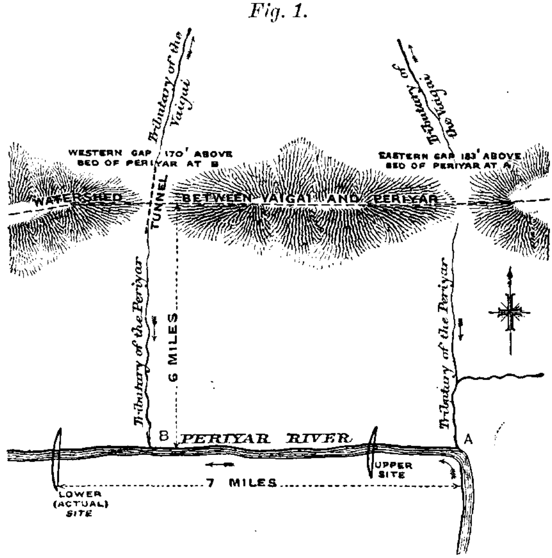
In India the Acquisition of Land Act saved a great deal of trouble to which English engineers were subject; but unfortunately land could not be taken under that Act because Travancore was an independent State, and the matter had therefore been the subject of negotiation. With regard to the material of the dam, the mixture of rubble and concrete, the arrangement of the rubble was much more uneven than appeared from *Fig. 2*, p. 143. It was not really a series of straight lines, either horizontal or vertical, but was joggled and left uneven in every way. He did not, however, attach great importance to the difference of consistency between the rubble and the concrete. They were nearly the same material, and he did not believe there was appreciable inequality of settlement. There was nothing to be feared in regard to the two materials separating from each other. He agreed that for many reasons it would be desirable to have a movable dam on the escape. It would certainly give increased storage and save a certain amount in the construction of the dam, but after thirty years' experience in public works in India he did not believe in any work of importance being allowed to depend upon apparatus that required to be worked at the right time by native subordinates. If it was desired to prevent a dam being topped (whether of masonry or earthwork) the apparatus should be absolutely automatic. In many tanks in the Madras Presidency there were what were called dam-stones on the weirs, the intention being that they were packed up with sods and turfs to raise the water above the level of the sill of the weir in dry weather. At the approach of the monsoon they were supposed to be cleared to allow the flood-water to escape, but they were never cleared by any chance, and he believed he was within the mark in saying that two-thirds of the breaches of tanks in South India had arisen through the existence of those dam-stones. In every instance where he had the power to do so he had had them removed. He would rather spend a little more money in securing absolute safety than save expense at the risk of the whole structure. With regard to the quantity of storage necessary he had said in the Paper that it was about 7,000 millions; the actual storage was 6,815 millions, and included the whole of the losses to which Mr. Hall had referred. It included the quantity necessary to produce the flow through the cutting, and all the loss by evaporation, which was enormous. The latter had been taken, not at 3 feet, but at $7\frac{1}{2}$ feet per annum. Since the beginning of the work, careful records of the discharge of the river had been taken month by month, and he had kept a record showing what the state of the reservoir would be, supposing it had

Colonel Pennycuick. been completed in April 1889 and irrigation had been going on from it, the supply coming month by month; and allowing for the loss by evaporation, not only from the lake itself, but also in the passage to Madura, as well as the amount drawn off for irrigation, the result showed that with a full supply used for irrigation the water in the lake would never, except for a few weeks in 1894, one of the driest years on record, have fallen below about 125 feet above datum, or about 12 feet on the cutting. As to the depth required to give discharge through the cutting, although there was next to no fall the first 2,000 feet or 3,000 feet, the greater part of it was in earth and it was very wide, being, in fact, more an arm of the lake than a cutting. He entirely agreed that an earth-bank across the saddle on the left bank would have been preferable, and had he known all the physical facts at the time the work was begun he should have adopted that course, but it then appeared that the rock was as shown in the right-hand part of the section of the saddle, *Fig. 1*, p. 142, and it was not until later that a fault was discovered towards the left flank, and then there was not time to make any alteration. A whole season would have been lost in attempting to construct an earthen dam. A good deal of masonry had been completed and the best had to be made of what at the time appeared a difficulty. He was bound, however, to say that the result was perfectly safe. He had acted with a full knowledge of the conditions, and there had not been the slightest sign of slipping in the bank since its completion. He could imagine no more insane plan than attempting to make an earthen bank abut against the back of a flat masonry wall. The wing-wall shown in *Fig. 5* was stepped; it had buttresses every 10 feet and there was not a flat joint 6 feet square between that and the earth from one end to the other; there was no puddle. In India very little puddle was used; the way in which the earthwork was carried out practically made puddle of the whole thing. The material was not tipped from a large wagon, but it was carried in small baskets and trodden by the feet of the workmen; and unless the soil was very bad indeed (which it was not there) puddle was not necessary. The test-blocks referred to by Mr. Deacon were cubes. The criticisms of Mr. Binnie were directed rather to the Paper itself than to the works which it described. No doubt there were many points of interest that might have been discussed in more detail, but it was by no means easy to make a selection in this respect, and to have discussed fully every point connected with a work of this class would require, not a Paper, but a volume. The

Colonel Pennycuick.

Paper was not, however, quite so deficient as Mr. Binnie implied, the average and minimum discharge of the river being stated. The drainage-area was 305 square miles and the average rainfall was, he believed, about 90 inches per annum. The discharge of the river for the ten years during which records had been taken varied between 22,416 millions of cubic feet, representing 32 inches over the whole drainage-area in 1894 (a year of abnormal drought), and 54,640 millions of cubic feet, or 78 inches, in 1891, the average being a little over 50 inches. The ratio of the run-off to the rainfall would appear large, but a large

Fig. 1.



SKETCH MAP OF WATERSHED BETWEEN THE VAIGAI AND THE PERIYAR.

part of the drainage-area was occupied by steep hills with no great depth of soil overlying the rock, and there was reason to believe that the rainfall in the upper or southern portion of the basin, at present almost inaccessible, was greater than at the stations on the lake, where the rainfall-register had been kept. The sketch map, *Fig. 1*, would assist the reply to Mr. Waring's remarks as to the site chosen for the dam. The general direction of the River Periyar was from south to north, until about 7 miles above the site of the dam, when it turned abruptly to the left at right angles, and ran almost due west to about 1 mile below the dam, after which it turned

Colonel Pennycuick. slightly to the north again, and ran about west-north-west to the sea. During the 8 miles of its westerly course the river was within about 6 miles of the watershed ridge, and in this 8 miles were two remarkable depressions in the ridge which was everywhere else between 1,000 feet and 3,000 feet above the river-bed. At the most easterly of these depressions, which was due north of the great bend, the watershed ridge was 183 feet above the bed of the river; at the other, which was about north-north-east of the site of the dam, the difference of level was only 170 feet. Both depressions were at the head of tributary streams, which now formed arms of the lake. It was abundantly clear that it was only at one or other of these depressions that the watershed could be crossed without prohibitive expense in tunnelling, and that the dam should be as close as possible to the mouth of the tributary stream leading to the depression chosen for the passage. To the west of the upper tributary there were three good sites, of which the best was about ½ mile below it, and this was the site at which it was originally proposed to construct the dam. Later investigations showed clearly the enormous advantages of the western depression, and for this the only practicable site was that actually chosen, which was about 1 mile below the mouth of the tributary stream, the fall of the river in this distance being about 3 feet. In the 6 miles between the two tributaries it rose 31 feet more, and in the 6 miles above the upper tributary it rose no less than 150 feet. The valley between the two sites was flat and open, and contained numerous wide tributary valleys, giving enormous advantages in the way of storage. How great these advantages were might be inferred from the fact that a dam 160 feet high at the lower site impounded more than double the quantity of water impounded by one 220 feet high at the upper site, while all the advantages of facility of access were on the side of the lower site. The propriety of placing the dam higher up the river had been considered, but it was shown conclusively that this course, in addition to sacrificing more than half the drainage-area of the river, would cost considerably more than that adopted, as the only way of crossing the watershed would be either by a tunnel at least 10 miles in length, or a contour channel, the cost of which would be even greater, while the cost and difficulty of maintenance would have been excessive. It might be mentioned, in proof of the advantages of the site actually chosen as regards the water impounded, that the Furens dam, which was almost exactly the same height, impounded 68 millions of cubic feet, or just one-hundredth of the available storage of the

Colonel Pennycuick.

Periyar dam, while the cost of the latter was less than £14 per million cubic feet of total storage, and £27 per million cubic feet of available storage. He knew of no dam which gave comparable figures. He thought Prof. Unwin had mistaken the deep chasm in the river-bed, mentioned in the Paper, and clearly shown in the section, for the river-bed itself. The latter was 200 feet wide at normal water-level, and over 300 feet at high flood-level. But it was the length at the top and not at the bottom which governed the possible radius of curvature of a dam, and this length was 1,300 feet. No conceivable radius of curvature would allow the section of the dam to be reduced without an addition to the length, which would far more than outweigh the saving by such reduction. He was sceptical as to any advantage to be gained from curvature as regards the effect of changes in temperature, which could be, and were, quite sufficiently met by the elasticity of the material used in this dam, whatever might be the case in the more rigid Portland cement generally used in England.

Correspondence.

Mr. Bruce.

Mr. Fairlie Bruce considered the objections of the Indian Government to a tunnel outlet, for the discharge of flood-water, quite inexplicable. A suitable tunnel could with ease have been constructed through the body of the dam at or near its base, and could afterwards have been plugged in the ordinary way. A permanent outlet sluice would also have been of great service in the event of its being necessary to empty the reservoir for repairs. The risk, apart from the question of convenience, of such an outlet would have been much less than with the method of disposing of flood-water described in the Paper. The manner adopted for dealing with springs appeared risky, as diminishing the resisting power of the dam, and for other reasons. If it was impossible to cut them out, the safer course would appear to have been to have drained them to the outer face. It would also appear that the dam was not connected to the rock either at the base or at the flanks, frictional resistances being solely relied upon. This was not in accord with usual practice. As the result had been successful, however, possibly the Author was justified in the course he had adopted. Corresponding particulars of the cost of tunnelling on the Blane Valley section of the Loch Katrine