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. Colonel Pennycuick.

Correspondence.

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 Mr. Bruce.

Mr. Bruce. Aqueduct, in new red sandstone, were given in the following Table:—

MACHINE DRIVING.

	Cost per Cubic Yard. s.	d.
Labour (1·34 cubic yard to 0·95 cubic yard excavated per day)	5	9
Plant, horses, &c.	1	9
Explosives and light	2	2
Total	9	8

HAND DRIVING.

	s.	d.
Labour (0·76 cubic yard to 0·66 cubic yard excavated per day)	7	9
Plant, &c.	1	6
Explosives and light	1	2
Total per cubic yard	10	5

The cross-sectional area of the tunnel was about 10½ square yards.

Mr. Collignon. Mr. E. COLLIGNON, of Paris, admired the method of procedure adopted in the important works described in the Paper. The section of the dam appeared quite suitable, and the thicknesses sufficient to assure the general resistance of the work to the hydrostatic pressure. He regretted, however, the whole mass had not been constructed in masonry; much would thereby have been gained in homogeneity, durability and security. The courses might have been laid perpendicularly to the resultants of hydrostatic pressure and weight, to aid the equilibrium of the dam, which might have been constructed in plan of such form that the pressure of the water would tend to close the joints. The mass of masonry and of concrete was, on the contrary, exposed to disintegration under the action of unequal settlement, and the concrete was liable to become fissured in directions which could not be foreseen and which might act prejudicially as regards the preservation of the dam. The adoption of masonry for the whole of the work would not have necessitated a much greater outlay. The extreme thickness of the work was limited to the bottom portion, where the valley was very contracted, and where the space to be filled was consequently reduced to a short length, transversely to the valley. Again, the width of the dam at and near the crest was so reduced that it was little, if any, greater than the thickness of the two masonry facings.

Mr. J. GAUDARD, of Lausanne, remarked that although of smaller dimensions than that at Periyar, the dam at Verdon[1] had also given rise to difficulty, despite the tunnels pierced through the rocky hill-flanks for the diversion of the water. The season suitable for foundation-work was found to be limited to three or four months, when the water was at low level; and one year had been lost owing to unexpected floods. A thickness of 23 feet of gravel had to be excavated in order to form the foundation mass of concrete resting on the solid rock, and the leakages through the lower part of the cofferdam necessitated considerable pumping. The site was divided into three trenches by four lines of sheet-piling at right angles to the river. The excavation and the concreting were first carried out in the down-stream, then in the up-stream, and lastly in the central division. The dam was of masonry, 36 feet high, and formed a weir with a stability calculated to carry the overflow of a sheet of water 16·4 feet in thickness. It was curvilinear in plan, its ends being let into the rocky sides of the ravine. During its construction a temporary breach 16·5 feet wide had to be made near the end at the right bank to allow of a supplementary escape for the water. The semi-cylindrical wrought-iron caissons employed by the Author for stopping the flow of water through the vents, or orifices of discharge, arranged in the up-stream face-wall of the Periyar dam, recalled the method employed in repairing the quay-walls at St. Nazaire by a portable cofferdam placed with its open face against the face of the wall.[2] Being of timber the coffers in that instance were not semi-cylindrical, but were formed by three adjacent planes, and did not extend from the top to the bottom, but could be placed in position at any desired height, the lower end being closed by a tapering base, and the vertical edges being provided with flanges for attachment. The cylindrical sluice of the tunnel discharge, *Figs.* 6, p. 154, situated in the main dam, setting free instantaneously a large effluent volume with the minimum expenditure of raising power, was analogous to the barrel-sluice applied by Mr. A. Fontaine to locks. In the Moraillon type of cylindrical sluice it was not necessary to raise the movable cylinder above the level of the feed, but only to a fixed stop, surmounted by a narrower tube. With regard to the construction of the Periyar dam partly in rubble masonry and partly in concrete, at the Furens dam,

Mr. Gaudard.

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[1] Annales des Ponts et Chaussées, vol. iii., 1872, p. 428.
[2] *Ibid*, 1888, vol. xvi. p. 780.

Mr. Gaudard. St. Etienne, it had been considered important to make the masonry as homogeneous as possible of rubble masonry in hydraulic-lime mortar, without any ashlar work, so as to avoid the possibility of fissures arising from unequal settlement due to the ratio of the stone and mortar being altered wherever ashlar took the place of rubble. Small parallel internal walls cutting through the base of the concrete mass were shown in *Fig. 3*, p. 146, but their purpose was not explained. Were they adopted with a view to increasing the resistance to percolation? The maximum pressures on the materials, and the method by which the Author had calculated the section of equal resistance of this colossal wall were not stated in the Paper. The question had much exercised French engineers, many of whom had prepared sectional types.[1] In 1892 the "Société des Ingénieurs Civils" had published the section recommended for the Chartrain dam, as the result of the investigations of Professor P. Guillemain.[2] In Italy, Mr. G. Crugnola had published Papers on reservoir dams, and after the catastrophe at Bouzey Mr. Dumas had collated[3] the particulars of a large number of dams of various types of construction. The adoption of a facing in ashlar on the down-stream fall was advocated by Mr. C. Clavenad, it being understood that the bond between it and the body of the dam must be perfect. To counteract the oblique shearing strains he proposed laying the courses (in transverse section) in curves terminating normally to the inclination of the outer face of the wall, thereby counteracting the tendency to sliding. The avoidance of all joints was insisted upon by Mr. Rogeard, making the structure a monolith of cement concrete, similar to that adopted for certain repairing docks, and in enormous masses in the forts of the Meuse. The use of large blocks was preferred by Mr. Hétier. On the interior face, which he would make vertical, he avoided all horizontal courses, and employed random work, the stones being set with their longer dimensions vertical. On the other hand, he recommended on the exterior face the adoption of squared blocks with their beds normal to the face. He also advocated the use of external counterforts, the wall between the counterforts being in the form of a vertical channel. His calculations dealt with the question on the assumption of the mass being an elastic body, in which he

[1] Annales des Ponts et Chaussées, vol. xii., 1866, p. 212; vol. ix., 1875, p. 99; vol. xii., 1876, p. 574; vol. xvii., 1879, p. 196; vol. ix., 1885, p. 795; vol. xii., 1886, pp. 248, 550; vol. xiii., 1887, p. 595; vol. vii., 1894, p. 619; vol. x., 1895, p. 77.

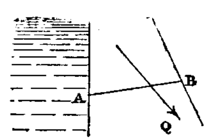
[2] See "Rivières et Canaux," by P. Guillemain, Paris, 1885.

[3] Le Génie Civil, 1895.

Mr. Gaudard.

limited the working strains to 9·14 tons per square foot in compression on the exterior face, and to 0·91 ton per square foot in tension on the interior face. In general, masonry was considered incapable of extension, in the application of the law of the trapezium for the resolution of forces on a joint; all joints subject to tension must then infallibly open—a serious matter in the case of a reservoir wall where water percolated, and must exercise dangerous sub-pressures. From this arose the rule that the curves (or resultants) of pressures must be kept within the central third of the whole. Thus Mr. A. Pelletreau (and also Mr. Williot) took as a type a triangular section with the interior face vertical (at least down to the limit of depth $= \frac{\text{resistance}}{\text{specific gravity}}$); this section, with curves of pressure limited to the third of the whole, internally or externally, according as to whether the reservoir was empty or full, was the smallest of the sections without extension. It did not depart much from the section of equal resistance, which was curvilinear. The section, *Fig. 2*, p. 143, of the Periyar dam, with its irregular profile on the lower face, approached still more nearly to that of equal resistance. Not content with the absence of elongation, under stress, of the masonry of reservoir dams, Professor Maurice Lévy was of opinion that the wall must be made sufficiently thick for maintaining in itself at all points of the interior face a pressure greater than that exerted by the water, so that the tendency was always to expel the latter. In the case of an imaginary joint, A B, *Fig.* 2, the weight of the superior solid A B C and the hydraulic pressure on A C gave the resultant Q, which in the normal state was balanced by the resultant of the reactions on A B, thanks to the variability of reactions which the deformation developed, according to the measure required to produce equilibrium. But if A B was a fissure into which the water found its way the liquid was not at liberty to graduate its effects, and, in obedience to the law of hydrostatics, it engendered an independent sub-pressure, which could not be balanced by Q. On this liquid lubricating film the mass A B C might slide, or even be lifted and overturned. If, on the other hand, the rotation engendered by the moment of the forces tended to reclose the joint, the reactions of contact between the surfaces of the solids came into play, and restored equilibrium. It might, however, happen that some film of water remained in an open part of the joint, whereby the ordinary law

Fig. 2.



Mr. Gaudard. of the resolution of forces was altered. If the pressure of the water was such as not to follow this law, the joint would close again more or less to compensate for the deficiency by an increase in the reactions of the adjacent solid parts. If, on the other hand, the water exerted a greater pressure, the joint tended to open wider, allowing the advance of the percolating water, augmenting the disruption and danger, the adhesion between the surfaces of the solids diminished, and became more concentrated on the arris B, as the latter tended to become the axis of rotation. But as the conditions of Prof. Lévy were difficult of attainment in dams of great height, he had suggested another expedient, also proposed by Mr. Le Rond and Mr. E. Coignet. This was to ensure the main core of the dam against contact with high-pressure water by the erection of a guard or masking-wall on the upper side, but connected with and abutting against the main core-wall by cross thrust-walls. On the up-stream face a series of spaces was thus formed, either as vertical wells, or if preferable, as horizontal galleries. The leakage which was unavoidable, through the thin masking-wall, would be carried off by a drain. These defence-walls, or screens, could, according to Mr. Le Rond, be constructed in timber, or according to Mr. Coignet in a series of grooves, or as vertical cylindrical arcs of cement concrete faced with continuous plating. These light arches butting against the ribs of the wall would be at the same temperature as the water, and their elasticity under compressive strain would prevent their cracking.

Much as the law of the trapezium had been contested, nothing seemed to have been found to replace it in current practice. The rule, for instance, might be followed of not resolving the oblique resultant of the forces into a normal force, and into a sliding force, but of taking it entirely as acting normally on the steps of a dentilated section instead of a slope section. This ought to give an excess of security, as resistance to shearing presented by those sides of the steps or dentilations parallel to the lines of force was neglected. The most prominent among the criticisms passed upon the law of the trapezium demanded that it must not be confined to the consideration of horizontal joints but must be applied to the imaginary lines of the joints in diverse directions. It had been shown by Mr. Galliot[1] that the tangential component of oblique pressures, ordinarily neglected, exerted in reality a very prejudicial action. But the theory became so

[1] Annales des Ponts et Chaussées, vol. vi., 1893, p. 111.

complex when it was investigated that it seemed improbable that the simple method of procedure would be abandoned, merely corrected for better or worse by arbitrary or empirical coefficients. It was by employing these approximate methods that engineers had adopted in the calculation of dams pressures varying between 5·5 tons per square foot to 12·8 tons per square foot. At the fifth Congress of Inland Navigation the opinion expressed was that it should be 11 tons per square foot. In the Periyar dam, *Fig. 2*, p. 143, at a depth of 150 feet below the surface of the water, the breadth between a vertical dropped from the interior edge of the crown and the outside face was 120 feet 6 inches, or, say, about 128 feet, including the interior batter. That thickness had been assigned to a depth of about 159 feet by Mr. T. B. Krantz, admitting a pressure of 5·5 tons per square foot; to 138 feet, with a pressure of 5·5 tons per square foot; or to 126 feet, 7 tons per square foot, by Mr. Clavenad; to 130 feet, 7·3 tons to 8·2 tons per square foot, by Mr. Crugnola; to 121 feet, 7·3 tons per square foot, by Mr. Hétier; to 117 feet, 9·14 tons per square foot, by Mr. Guillemain; and to 107 feet, 9·14 tons per square foot, by Mr. Pelletreau. The variations were explainable by certain divergencies in the process of calculation, to the density attributed to the masonry, etc. In the case of the Periyar dam, the working pressure appeared to be about 7·3 tons per square foot. It was to be regretted that the dam was not made curved in plan, as that would (although it was not the case at Furens) have allowed a considerable reduction in its thickness. Mr. Gaudard.

A dam might offer resistance in three ways—

(1) As a straight wall resisting by gravity, overturning, and by friction, sliding on the courses. The stability of this system was threatened by the existence of horizontal or sloping fissures, but not by transverse vertical fissures, for every section resisted by itself as the whole.

It was even proposed by Mr. Le Rond to construct such walls divided into segments with an elastic filling in the joints, with a view to the avoidance of the formation of irregular fissures due to contraction in severe winters.

(2) As an elastic plate or slab held fast at a portion of its perimeter, as in the case of a narrow gorge, deep and rocky. These conditions gave rise to mathematical considerations, of which Mr. Souleyre had given an account.[1] The maximum of flexure affected the middle of the free edge, and, notwithstanding the high pressure of the water in the bottom of the ravine, the resist-

[1] Annales des Ponts et Chaussées, vol. xviii., 1889, p. 442.

Mr. Gaudard. ance offered would be far from demanding the enormous thicknesses called for to meet the exigencies of the first theory.

(3) Lastly, as the rings of a horizontal arch. If the sides of the valley offered abutments with a solid springing or skewback (as was the case at Periyar), the curved wall, convex on the upstream side, would possess considerable strength. It was by adopting this method that the Bear Valley dam [1] could be reduced to a thickness of 8 feet 6 inches under a head of 43 feet of water. In a curved wall, the transverse joints would be of less importance than in the case of a straight wall, as they tended to close themselves under the pressure of water; and, the horizontal fissures, so dangerous in the case of a straight wall, were of no importance in a curved wall.

But what would happen to a curved dam if it were not firmly grafted into the rock at its ends? It would still offer great advantages. Supposing the dam to be of the same height throughout its length, and not to be fixed at the ends, the horizontal courses, considered as rings of an arch, held together, owing to their mutual fixture, which again rendered dangerous the percolation of water through horizontal fissures. But the weight of the courses, and the locking which resulted, converted the structure practically into a monolith without tendency to dislocation, and would be sufficient to insure against both sliding and overturning. The overturning must be around a rectilineal axis, along the chord of the curve at the foot of the structure; the effect of the curvature was thus to place the greater part of the mass of the wall further from the axis, and to increase the moment of resistance or stability opposed to the pressure of the water.

There seemed scarcely any instances of curved dams falling. That of Puentes was formed of three rectilineal portions; the Bouzey dam was straight, as also was the Habra dam, overturned in 1881, and the Cheurfas and Sig dams destroyed in 1885, whilst the Chéliff dam successfully withstood the trial, thanks to its curvature of 492 feet radius. The Sonzier dam, at Montreux, destroyed in 1888, was a straight wall, this character being adopted as a necessity, owing to its forming one side of a rectangular reservoir. A settlement of the foundation had produced internal cracks, and led to its being overturned. It appeared from the Paper that at one time it had been contemplated to construct the Periyar dam of earthwork. Unquestionably the Author did well not to take that risk. It was true Mr. Decoeur had given it as

[1] Minutes of Proceedings Inst. C.E., vol. ci. p. 357.

his opinion that dams of earth might be rendered more reliable than those of masonry, which were at the mercy of fissures produced by settlement, effects of varying strain, contractions due to cold, earthquakes, &c. Instead of ramming and puddling the earth with an addition of lime, he obtained as high a degree of stability and greater elasticity by mixing with the earth refuse vegetable fibre, such as leaves, grass, and rushes, ground in a mill similar to that used in preparing the pulp in paper-making. Many of the ancient dams of India owed their high degree of cohesion to the extreme length of time occupied in their construction, such as would now be altogether out of the question. English engineers had been successful in constructing dams of earthwork, subject to as much as 100 feet head. On the other hand, in France, since the example furnished by the disaster at Sheffield in 1864, it had been considered risky to exceed 50 feet, and in place of forming the interior slope with a pitched sloping surface, it had been considered preferable to construct it in a series of inclined steps, forming low vertical faces and benches, which, by confining to certain portions the formation of fissures, should they be formed, in case of settlement, rendered them more easily discerned and repaired. Mr. Gaudard.

As regards the means adopted for determining the alignment of the Periyar Tunnel, he recalled the method of procedure of a similar character, but of much greater extent, adopted for fixing the direction of the St. Gothard Tunnel.[1] The Eckhold omnimeter, like the Porro-Moinot-Goulier tacheometer, was an instrument of great value for fixing, by simple sights and corresponding vernier readings, points marked by pegs or signals. In Switzerland, for the detailed topographical surveys for filling in the geodetic figures, great use had been made of the plane-table and stadium, ruled to accord with the Wild method, such as that constructed by Messrs. Kern of Aarau, Switzerland. By their means were transferred directly to the paper, on the ground, with their levels, all the elevated points, and the surveyor, in carrying on his work, was enabled by its aid to execute a faithful and complete representation of the surface in view.

Colonel J. O. Hasted, through whose hands, as Chief Engineer for Irrigation, and Joint Secretary to the Government of Madras, the designs for the works had passed to the Government of India, desired to offer the Author his warmest congratulations on the successful completion of this great undertaking. A name which he thought should not be omitted from mention in connection Colonel Hasted.

[1] M. Pestalozzi, Die Eisenbahn, 1877.

Colonel Hasted. with the work was that of Captain, now Colonel George Massey Payne, who some thirty years ago had been engaged in taking levels for the work, and who was the first, he believed, to recommend a masonry dam. His work was done under considerable difficulties in unexplored jungles, and his reward was jungle fever. He thought the enormous difficulties in carrying out these works would not be appreciated from the modest account given of them in the Paper. All machinery had to be arranged for months, if not years, before it was required, and to be specially designed so that it could be conveyed on country carts over soft roads. If anything broke down, or even an additional pump was needed, it took weeks or months to obtain what was necessary. Skilled labour had to be imported, men taught their work, and ever present among the staff and work-people was the deadly jungle fever, and occasionally cholera. Special reference had been made to the refusal of the Government of India to allow a tunnel in the rock at about river-level for the purpose of passing the discharge of the river during the construction of the dam. Many of the difficulties which were experienced in the construction of the lower part of the dam would no doubt have been prevented by such a tunnel, but by a sanctioning authority the tunnel must be considered a hole near the bottom of the dam, and a possible source of danger which, when such an immense head of water had to be dealt with, was a very serious consideration. By means of self-acting sluice-gates the velocity in the tunnel was to be restricted to 20 feet per second, but there would always be a risk of damage to the self-acting machinery, and if anything went wrong when the dam had been raised to near its full height an almost irresistible force would be let loose at nearly the bottom of the dam. In view of these considerations it was deemed desirable that rather than there should be an opening left at the level proposed, any and every difficulty in construction should be faced. The proposed gates were much the same as those which had been described at the entrance to the large tunnel. The principle was similar to that of the Stoney equilibrium sluice shutters. In the one case the pressure was from outside inwards, and in the other from inside outwards. There was nothing to be said against them. He had always been in favour of the dam being constructed of concrete, and was glad to learn that the great mass of it was of this material. He would like to know whether any leakage had been observed below the dam, and if so, where? It was eminently satisfactory that the dam, while the upper portion of it was still green, had stood an extraordinary flood, an extreme test, without any sign of weakness.

Mr. F. KREUTER, of Munich, had no doubt that, owing to the considerable resistance to crushing of the material, as stated in the Paper, the structure of the dam was of abundant safety throughout. As to the tunnel, he hoped the fissures met with during its construction, and much more those created by blasting with as high an explosive as gelatine, would not make it necessary to line it with masonry. From the fact that it had not been found necessary to provide means to prevent the escape of water through the natural fissures, these might be concluded to be of slight importance. The numberless imperceptible cracks, however, which were infallibly produced by the use of high explosives, had, at least in Germany, hardly allowed one tunnel to be left rough, as blasted out, even in the toughest and most solid rock. It must be borne in mind, however, that in the Periyar Tunnel the operation of blasting had been performed with great caution. Mr. Kreuter.

Colonel PENNYCUICK, in reply to the Correspondence, did not know on what grounds Mr. Fairlie Bruce supposed that "the dam was not connected to the rock either at the base or flanks"; it was carefully let into the rock on both flanks by irregular cuttings in the rock; in the bed of the river the natural face of the rock was so jagged and irregular that little or no artificial cutting was necessary; but throughout the whole area formed by the meeting of the masonry and the rock there was hardly a square yard in which the connection depended upon frictional resistance alone. He thought Mr. Collignon was under a misapprehension as to the reason for making a large portion of the dam of concrete; this was not done for the sake of economy, there being in fact very little difference in the cost of the concrete and rubble, but for the sake of speed; the number of masons available was the principal factor in fixing the proportions of the two materials, and to have constructed the whole dam of rubble would probably have added at least two years to the time occupied in construction. As to any risk from unequal settlement, he could only repeat that he utterly disbelieved in the existence of any such risk; the two materials were practically identical in composition, the proportion of stone not differing by more than 5 per cent. at the utmost, and there was certainly no measurable difference in the rate of settlement. There had been ample opportunities for observing any such difference, if it had occurred, but not the smallest indication of any had been seen. He did not see how masonry could be laid in courses normally to the direction of resultants which varied from day to day with every fluctuation in the level of the water; but apart from this he considered anything in the shape of a "course" to be objection- Colonel Pennycuick.

Colonel Pennycuick.

able, and the greatest care had been taken to avoid courses in the masonry actually used. The parallel internal walls noticed by Mr. Gaudard had been put in to divide up the area into sections for convenience of construction. He intentionally refrained from discussing the principles on which the calculation of pressures had been made, as the subject was altogether too complicated and too mathematical to be dealt with in a descriptive Paper. A note on the subject was attached to his original report[1] on the dam written in 1882. It would be seen from what had been said above that he considered courses objectionable and agreed with Mr. Rogeat in considering that the structure should be a monolith, which in point of fact it was, as regards both the rubble and the concrete portions. He was at one time in favour of the use of large blocks, but it was found in practice that the use of any stone larger than could be carried by two men gave more trouble than it was worth, and the smaller the component parts, the more the work approached the monolithic character. The guard wall advocated by Mr. Gaudard and by Messrs. Le Rond and Coignet would no doubt be useful, but he doubted whether its cost might not be more usefully spent on the main wall. With regard to the suggestion that advantage would be gained by a curved plan, he wished to repeat emphatically that he utterly disbelieved in the advantage of this form. In the particular case of the Periyar dam no radius of curvature less than about 2,000 feet could have been used, and if those who imagined that a reduction of pressure for a given thickness, or a reduction of thickness for a given limit of pressure, could be obtained by considering the dam as an arch, would take the trouble, as he had done, to calculate the actual pressures on this theory, they would find that for a given section, with any practicable dimensions, these pressures greatly exceeded those produced in the straight wall. The instance Bear Valley dam was beside the question; there was no analogy between a dam 43 feet high and 450 feet long, and one of four times this height and three times the length, and as a matter of fact the pressure on the masonry of the Bear Valley dam was four or five times that in the Periyar dam, so that the success of the former merely proved that masonry would bear a much greater pressure than it was thought wise to allow in a large work; a point on which he for one had never had any doubt. Of the dams mentioned by Mr. Gaudard, that of Puentes failed from the yielding of the soil on which it was built; that of Bouzey from imperfect design and

[1] Records of the Government of India Public Works Department, No. ccxv. Madras, 1886. Appendix I., p. 24.

weak foundation, aided in all probability by the action of frost, an action to which the Periyar dam was not exposed, and which in any case was not better resisted by a curved wall than by a straight one. The Habra dam failed from bad workmanship. He was not sufficiently acquainted with the history of the Cheurfas, Sig, and Chéliff dams to be able to say how far the two former would have been safe if curved or the latter have failed if straight, but with regard to the Montreux dam it was clear that the failure resulted from settlement of the foundations, and it was not shown that this would have been avoided by making it curved in plan. The admirable cohesion of the earthwork in Indian dams, noticed by Mr. Gaudard, was not due so much to the time occupied in their construction as to the mode of construction, the earth being deposited in very small quantities and constantly trampled by the feet of the workmen. Modern work was just as good in this respect as ancient; in the case of the Red Hills reservoir, which supplied the city of Madras with water, in which a trench ½ mile long and 50 feet deep was caused by a cyclone in 1884, and which he had restored in the following year, only eight months were occupied from the beginning of the work to the time when the reservoir was again completely filled. In reply to Mr. Kreuter, no difficulty had been experienced nor was any anticipated in consequence of the fissures existing naturally in the rock, or produced by blasting. It must be borne in mind that in the first place the slope of the tunnel was such that the required discharge was produced with little or no head beyond that due to the actual depth of water (7½ feet), and that any water which did escape through fissures must return to the valley in which the water was to be used; whether it reached the valley by means of the tunnel or through fissures in the bottom or sides of the latter was a matter of indifference. Colonel Pennycuick.

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2 February, 1897.

Mr. JOHN WOLFE BARRY, C.B., F.R.S., President, in the Chair.

It was announced that the several Associate Members hereunder mentioned had been transferred to the class of

Members.

Robert West Holmes.
Albert James Humby.
Robert Bridges Molesworth, M.A. (*Cantab.*)
John Mitchell Moncrieff.
Howard Devenish Pearsall.
Percy Crosland Tempest.
Beresford Gahan Wallis.