Mr. Strange.

course approved of by Mr. Hill. There was no question but that water passed through Indian puddle, and, although he was aware that English clay was a greatly superior material, he was surprised to learn it was absolutely staunch. He would be less surprised to learn that the leakage from it was carried off, unperceived and underground, for considerable distances through the stratified layers which were plentiful in England, but were rare in the Deccán. The self-drainage of the rear of the dam recommended dealt with a very small quantity of water, but it was essential to pass that out and not to imprison it in the dam. He desired to alter his statement (p. 161) that the saturation of the up-stream slope of the dam was "very dangerous" to "very undesirable." Such saturation must diminish its stability and make it as safe as a dry one; it must be flattened, and more material must be used. The drystone toe as designed was practically solid, being packed with clayey murum (p. 162), and water was kept out of the base by the concrete toe wall which was founded into rock. Experience in Bombay had shown that culverts under the dam were quite safe, but, to make assurance doubly sure, he had recently designed certain reservoir outlets as headwalls on the centre lines of the dams (Fig. 20, p. 183), and believed that, when ordinary precautions were taken for uniting the masonry and earthwork by long staunching walls with cross walls, rather than by forming wing walls, this design was superior to all others on account of its accessibility. Further, it allowed of large sluices being used to keep the reservoir low during the monsoon, and thus tended to diminish its rate of silting up, and brought the flood-absorptive power of the reservoir earlier into play.

Correspondence.

Mr. Bell.

Mr. J. R. Bell remarked that, although it was many years since he served in its Irrigation Branch, he would say that the Public Works Department would derive much gratification from the reception of the Paper by the Institution. From the point of view of famine prevention, both railways and canals had done much to alleviate distress; indeed, the local famines which wrought such terrible evils so late as 1867 and even later, had already been minimised, and owing to the progress made in both developments, it was only when dearth pervaded several parts of the entire peninsula simultaneously, that it was in these days heard of at

Mr. Bell. home. Happily the famine of 1897 seemed to be at an end. It might be interesting to mention that Mr. Joyner, the Superintending Engineer for Irrigation for that section of the Bombay Presidency in which the Author seemed to have spent his service to so much advantage, had been decorated by the Government of India for his famine service and specially thanked by that of Bombay for the promptness with which he prepared projects for large works when a concentration of labourers became urgently necessary in the hill talukas of Poona and Satara, owing to the reluctance of the distressed people to go to a distance. To so employ them on works which might serve to avoid future local scarcity in places where railways were never likely to penetrate was the object in view; and although it could not be supposed that, in that time of stress, all the more advanced refinements of design to which the Paper drew attention had been adopted, it was surely a good thing if this appeal for guidance succeeded in strengthening the hands of those who sought to combine progress with soundness in a peculiarly difficult branch of professional practice. Many points of design referred to in the Paper were not yet reduced to practice, while others, like the elsewhere well-known method of closure by level stages, seem to be moot points in Bombay. Mr. Bell was very far, and so he felt sure was Sir Alexander Binnie, from hinting at any serious disagreement between those who, like Mr. Joyner and the Local Government, had to decide, and any ardent junior "progressive" who, like perhaps the Author, had suggestions to offer. Such works were for the most part remote from railways and from even such skilled labour (other than that of the nomadic tribes of stone-quarriers and earth-diggers known throughout the Deccán as wuddars) as was found in the towns. The only possible building materials were those so clearly described in the Paper:—(1) Basaltic stone, with its conchoidal beds and its often treacherous liability to perish between wind and water, (2) disintegrated trap, ranging from hard "murum" to "black-cotton soil" through a whole gamut akin to the range of shales, clay shales, and clays, (3) nodular limestone or "kankar," and (4) river sand (the two last scattered and in very moderate quantities, but the two former unlimited), form the entirety of the indigenous resources of these districts. There was no timber bigger or better than firewood, no fuel but that and charcoal. Staging was commonly built, if its use could not be avoided, with Moulmein teak or with Oregon pine, railed hundreds of miles from Bombay and then carted scores of miles uphill to such works as these. Ironwork was either imported from

Mr. Bell.

home or made up in Bombay, where the leading firms did excellent work at very reasonable prices when not hampered by plague or strikes. These local peculiarities might help to explain why certain devices were adopted, less from choice than necessity, and might serve to show the especial sense in which the Bombay Irrigation Department was adapting the resources of Nature to the use of man. When all was done these great reservoirs could never profess to compete with the quasi-perennial canals in the plains. There must be many such canals that delivered between 200 million and 300 million cubic feet of water to the land in each 24 hours, discharges that would empty any one of these reservoirs in a fortnight, reservoirs that were intended to hold out for two years, both against irrigation and evaporation. The latter loss must amount to several vertical feet in the year, and especially in a year of drought and hot winds. In some of the very shallow tanks of the Madras Presidency, Mr. Bell had known the hot winds to lick up, in conjunction with moderate leakage, $\frac{1}{2}$ inch in 24 hours, but it might be hoped that this was an exceedingly abnormal experience. The leakage from such reservoirs as those in the Paper could hardly be called a loss, it was at most a modest form of compensation. In no case, however, could reservoir irrigation compare favourably on commercial grounds with canal irrigation. If Government must feed agricultural labourers to keep them from starving, it must exact a labour test of some kind, and labour that might avoid any future need of so feeding them at all was certainly the best way to treat what was, in any case, a bad job. The Western Deccán rainfall did not lend itself to making many "tanks," as the shallow embanked reservoirs common in Madras were called, nor to the still more elementary native system of Orissa, where each field was its own tank, and retained its own rainfall, till some evaporated and the rest was absorbed, in those fortunate seasons, when the rainfall filled the bunded enclosures, without breaching them in series. The Madras village tank was a compromise between such bunded-field and the reservoirs under discussion; the bulk of the tank-water was led to the fields below by open ducts, and would usually irrigate from two to three times the tank's own maximum area. As the water got drawn off and evaporated, the villagers followed it up, or rather down, with cultivation in the tank-bed, thus utilising at once the silt's fertility and the water of absorption, so that, in all, a shallow tank would serve to cultivate three to four times its area in normal seasons of moderate rainfall. In such districts, the bund of a village tank

Mr. Bell. was seldom higher in all than the bare freeboard, which the Author's works demand, firstly, for an adequate depth of escape over the waste-weir, and secondly, for the waves which, in such mountain gorges (for the Western Ghats would be deemed veritable mountains in Great Britain), were suited to the Author's purpose. There were both waste-weirs and waves in village tanks, but the experience of centuries had led to the abandonment of sites where either difficulty had caused repeated disaster, and, in practice, the roughest-looking appliances sufficed to reduce the disastrous breaching in series of long chains of village tanks (mentioned by Sir Guilford Molesworth) to perhaps once in 50 years in any given valley of any large extent. The waste-weir or "calingula" of the village tank was exceedingly simple and ingenious. It was a substantial masonry weir with wing-walls across, where available, a rock-bedded outfall, and a number of stone posts, pitched about 2 feet apart, protrude a yard or more from the weir-crest. These dam-posts served as stanchions to uphold a wall of raw clay, which the cultivators built up in time for it to be staunch and sun-dried ere the rains top the masonry. If the latter rainfall came on gradually and unaccompanied by violent squalls, the depth of the dam-stones can thus be saved for irrigation purposes. If, on the contrary, the clay was overtopped, it washed away in no time and put the masonry weir in action. Accidents, with this arrangement, have occurred through the villagers trying to save a second supply of top-water after the temporary clay dam had been washed away early in the season. In that case, being unable to staunch the flowing calingula with clay, they had recourse to wattling or dam-boards, and thus risk the tank itself, on the chance of no second storm overtaking them at unawares. They were not alone in accepting a remote risk in the expectation of a substantial gain. And they were far from alone among the natives of India in trusting too much to blind chance and then blaming their gods or their rulers for the consequences of their own apathy. That was why he viewed the elaborate and ingenious device of a stepped-weir with no small misgiving. He regretted that he had not made himself acquainted with the details of Mr. Reinold's automatic shutter, which was seemingly put in action by filling its counterpoise chamber on emergency, but it was well to recognise that whatever of ingenuity and strenuous effort was proper for the work of an engineer in India, should be put into the business of construction while the whole was under the master's own eye, and not left to be exercised by others, and especially by natives in the course of maintenance. Suppose, one should say to oneself, that this work were left to subordinates or to the village elders to work, the question would then arise—not so much whether it could be worked properly, as, could ignorance or carelessness wreck it when its *modus operandi* had become a vague tradition? These dams were not like a railway, where fairly competent inspection proceeded almost continuously day and night. They were not even like the large canal headworks in the plains, which each employed a resident engineering staff. Without going so far as to disapprove of the Author's design for the proposed Málávedi weirs, and while admitting the saving virtue of applying a "breaching-section" (p. 161) where feasible, it was right to say that extreme caution should be used in adopting elaborate expedients for these escapes. It might be necessary, in any case (p. 179), to maintain a special establishment at one time of year, and there was little doubt that, for a time, and perhaps a long time, the automatic gates "can be made to act," the teak crest could be removed, and the under-sluices called into play with promptitude and success; but it might yet prove that, among such people, and in such places, simpler expedients would better stand the test of time, which was the true test of such engineering as exotic rulers like the British should attempt. In some ways the Author went beyond Mr. Bell, in his desire for a permanence that might minimize maintenance, and perhaps too far in proposing a continuous concrete revetment to overlay such a treacherous material as black-cotton soil, with its admittedly serious internal strains. He would leave the details of the proposed compound dam to specialists, merely mentioning that his own Deccáni experience did not lead him to expect that much of the trap rubble would disclose natural beds suitable for being laid normal to the slope or to any defined plane. The proposed front toe was, it would appear, a solid wall built in mud mortar, made of "clayey murum," and, if so, it might be suggested that it would be better to have the puddle-trench set under the rear part of this toe. It was not clear how far either of the analogies derived from Nature applied to the section of slope proper for such works as these. Fujiyama had a parabolic slope flattening towards the base, but it probably consisted of lava and pumice and might owe its lower flatness to the drifting of volcanic ashes in the wind and rainwash. All slips had the well-known ogee slope, but that was clearly attributable to dynamic effects where a semi-plastic mass slid on a lubricated slip-plane. The section of such slip-planes themselves was analogous to that of Fujiyama, but that profile did not prevent a fresh slip from starting so soon as the counterpoising weight of Mr. Bell.

Mr. Bell. the former slip's "nose" was reduced by erosion or denudation. The proposed flattening slopes followed the Fujiyama type and the old benched-slope was undoubtedly a rectilinear adaptation of the ogee of a natural slip. He had not heard of any serious attempt to cure a slip by adding more loading to its nose. Draining the lubricating slurry of the slide was the recognised panacea, but it seemed worth while to try overloading in cases where thorough drainage of the slide-surface was impracticable. If this be the first Paper yet discussed in the Institution, which had emanated from a member of the Coopers Hill recruitment of the Indian Engineering Service, Mr. Bell would venture to say that it was well worthy of that distinction. Nothing could well be more simple, ingenious, and satisfactory, as a preliminary revetment, than setting the pitching-stones with their broad, squared ends down, as described on p. 150. It was a perfect and yet simple solution of a difficult problem. He had seen so much trouble from ripples undermining pitching set face-up, that in river-training works, &c., he had ceased to employ anything but loose stone, ready to sink and disclose erosive undercutting. If the Author deferred concreting his pitching till it was well settled, and would then concrete it up in sections with free longitudinal and cross-joints, he would make a capital job of this part of his interesting and beneficent work.

Mr. Bruce. Mr. A. FAIRLIE BRUCE considered, as regards the puddle-trench, that unless there happened to be a fault in the line of the river bed where it crossed (when concrete might be used with advantage) there did not appear to be any essential reason why this part of the trench should be differently treated from the remainder, or why if proper care be taken it should be less watertight; the leaks, which seemed to exist more or less in almost all Indian dams, were probably to some extent due to the practice, alluded to by the Author, of leaving a gap in the centre for the escape of flood-water, which was afterwards hurriedly filled. It had for long been recognised by all waterworks engineers that all junctions in puddle-trenches, whether with the ends and sides or between one part of the trench and another, should take a wedge form, all re-entrant angles or vertical faces being carefully avoided. Where a perfectly watertight stratum could not be obtained it frequently answered sufficiently well to lay a layer of good concrete about 2 feet thick in the bottom of the trench, with a feather running along its whole length to make a good joint with the puddle. Any leakage which might take place passed below the concrete without any tendency to increase; it could then usually be collected in a well at the back of the dam, and led into the supply pipe. Whenever the concrete was used in the bottom of a trench, it should always be lowered in skips, and not thrown down or sent through a shoot, otherwise the materials separated, and the bottom layer consisted of nothing but dry stones. In the Tulsi and Vehar Lakes, in connection with the Bombay Water Works, there were one masonry and four earthen dams, all of which leaked to some extent, and had done so since their construction, without apparently doing any harm beyond the loss of water involved. If, instead of devoting care and expenditure to the formation of an elaborate system of drainage, it were expended on the construction of the dam, a better result might be obtained. If the English practice were more closely followed of only aiming at making the heart of the dam water-tight, and forming the inner half of hard material, mixing with a certain amount of small stones well consolidated, probably Indian Engineers would experience less difficulty in making dams tight, and slips so often complained of would not have taken place. He agreed with the Author in advocating a surface slope in the layers of the embankment towards the centre, though 1 in 10 seemed somewhat more than was required, and also in deprecating an excessive use of water. This was quite in accord with the best practice in England. In the Bombay dams most of the pitching had been set with the broad face uppermost, which was obviously a mistake; as, however, none were exposed to a long reach in the direction of the monsoon gales no damage had resulted. In the absence of large scaled drawings it was somewhat difficult to follow the Author in his description of what he calls a "stepped waste-weir," but it appeared to be unnecessarily complicated, which was to be avoided when it was remembered that it would have to be worked by more or less ignorant natives. They did not seem to have been tried by the Author. As regards outlet-works, many most successful culverts on the Edinburgh Reservoir and elsewhere had been carried through the dam itself. If they were built in a trench excavated in good hard material, it was as a rule preferable to building them in a tunnel where the work was more difficult to inspect. There need be no risk in carrying the culvert across the puddle-trench if it was supported on a concrete pillar having a side batter and with a good feather up the sides and over the top to stop any creep between it and the puddle. The culvert under the Tulsi dam collapsed soon after its construction 20 years ago, but beyond a trifling leak through it, no harm had been caused. The Vehar outlet pipe was originally laid Mr. Bruce.

Mr. Bruce. in a culvert under the main dam also, but after the accident to the Tulsi culvert it was abandoned and a tunnel cut through the hill at one end. The outlet sluices (if they could be so called), at both Tulsi and Vehar Lakes were glorified examples of the native plug, described by the Author, consisting in the latter case of a plug, 4 feet in diameter, lowered by chains into pipes projecting outside the tower with one of 6 feet diameter in the centre of the tower. When one of the pipes in the tunnel burst recently, it was found impossible to close them without the aid of a diver. Designs were at present being prepared to substitute sluice valves for them. Valves worked by rods running down the inner slope of the dam were almost as objectionable as the above, as the least subsidence caused them to be bent and jam, and there was no way of repairing them short of emptying the reservoir.

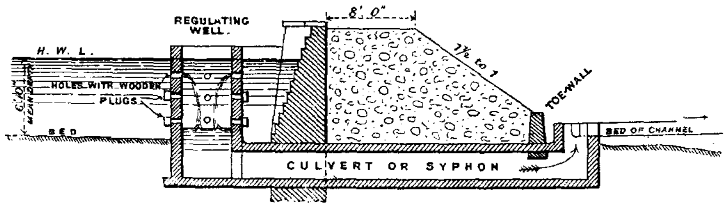
Mr. Croes. Mr. J. James R. Croes considered that the underdrainage of the embankment advocated by the Author constituted a feature of very doubtful propriety which, so far as could be learned from the Paper, had not been introduced in any dams heretofore built under careful engineering supervision. The Author propounded the theory that, "up to the centre line every precaution should be taken to prevent infiltration, while beyond this point, every facility should be given to the harmless escape of such water as has penetrated so far." To accomplish this, he recommended the construction of drystone drains along the centre line of the embankment, leading out to the toe of the outer slope. In the absence of experience and evidence to the contrary, it would appear as if this mode of construction would facilitate the leakage of water through the dam, and the creation of currents, and a steady flow through the saturated up-stream half of the embankment, and the washing out of the finer particles of that bank. If such particles were carried out through the drains, the flow of water would continually increase. If they only were carried part of the way to the outfall and clogged the drains, the result would be that the water above the point of stoppage would rise and saturate the bank above and come out on the slope of the down-stream face much sooner and with more disastrous effect than if the old-fashioned method of interposing every possible obstacle to its progress through the whole of the bank had been followed. It was difficult to believe that dams of the types shown in Figs. 8 and 9 would not be safer with the drains under the lower slopes of the embankments omitted, and the security of the bank made more dependent on what had been well termed "the abhorrence of water to a right angle" than on the affording of facilities to its flow. If, however, the Author's theory were correct and the water which had penetrated to the centre of an embankment had better be carried off in the quickest way, there ought to be a drain laid through the centre of the bank about 8 feet or 10 feet below the flow-line of the reservoir, and carried off to the natural surface at the ends of the dam. In an embankment not thoroughly watertight, that was the point where the danger of saturation of the outer slope causing slides was the greatest, and such a drain might lower the surface of saturation in the bank.[1] Where plenty of stone could be procured, and skilled labour was scarce, the type of dam proposed by the Author in Fig. 8, and termed by him a "compound dam," would seem to have many advantages. The construction of both of the toes of heavy rip-rap with the spaces well filled with clay would prevent the sliding which was most to be feared in such a high earthen structure. Mr. Croes.

Mr. C. H. Croudace observed, in reference to irrigation reservoirs in Northern India, that the average rainfall in Jeypore and Ajmere districts was about 24 inches, but in famine years it fell to 6 inches and less. Even in good years the rainfall was often erratic; falling on the catchment basin irregularly over small areas, which took the shape of narrow strips. Again, the rain might fall in light showers, and at other times in heavy downpours amounting to as much as 3 inches in the hour. Hence the available rainfall over a rectangular catchment basin of 5 square miles to 20 square miles had to be estimated with extreme caution, and must be based on careful rain-gauge observations throughout the basin. There were some fine old tanks built by the Rajput States prior to the British period; notably the large tanks or rather lakes at Ajmere, Odeypur, and Mandel, the dams of which consisted of a heavy facewall backed by earthwork. The surface leakage or percolation below the tank-bed and dam was found to be beneficial for the down-stream well irrigation (often for many miles), as it raised the spring level of the wells for a long distance down the drainage line on each side. Bearing this fact in view, Colonel Dixon, R.A., prior to 1857, covered the hill districts of Ajmere and Mhairwara with some hundred or more tanks or lakelets, which were of great benefit to the peasantry of the country. These dams were built in the narrow gorges of the hills of solid masonry throughout; but in the more open country or plains they consisted of earthen dams or "bunds," generally segmental in plan, *Figs. 34*, with an average height of between 15 feet to 20 feet in the centre, and Mr. Croudace.

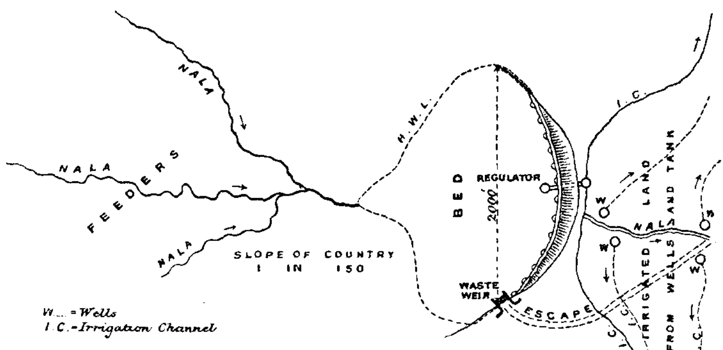
[1] Minutes of Proceedings Inst. C.E., vol. cxv. p. 158.

Mr. Croudace. varying from $\frac{3}{4}$ mile to sometimes 2 miles in length. The catchment basins varied between 1 square mile to, perhaps, 10 square miles, and the storage with an available rainfall of 4 inches would give from 8 million cubic feet up to 80 million cubic feet of water. Owing to the shallowness of many of the tanks, the net amount available for irrigation by flow was low, and their utility consisted mainly in the cultivated bed of the tank when dry and in the effect they had in raising the spring level of the wells in the

Figs. 34.



Cross Section of Dam.
Scale, 1 inch = 16 feet.



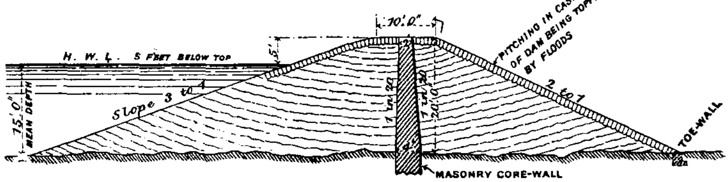
Plan, Ajmere and Mhairwara Districts.
Scale, 1 inch = 2,000 feet.

Dixon Type of Reservoirs in Rajputana, India.

rear or down-stream side of the dams, which acted as siphons in some measure. After the great famine of 1867–68, the Government of India took up on a large scale the tank irrigation of these districts under Colonel J. G. R. Forlong, Superintending Engineer, with Mr. Croudace and other engineers as his assistants. Similar work was also commenced by Lieutenant, now Colonel, S. S. Jacob, C.I.E., who since then had done so much for the economical and remunerative tank irrigation in that native state. Attempts had been made in the Ajmere district to make Colonel Dixon's old tanks watertight by introducing core-walls of puddle or masonry, but with poor results. At the same time the repairs or maintenance was taken over by the Government from the villagers, the result being that they neglected their tanks and had no self-reliance in emergencies, such as on the breach of a dam occurring from excessive floods. Several large projects were initiated by Colonel Keatinge, V.C., Agent-Governor, notably the Bheer Reservoir (to supply Nasirabad Cantonment), and the Beawr Reservoir, on which he had been engaged, near Beawr in Mhairwara, were constructed at great cost between 1870 and 1875; but were disappointing in their results in so much that the available rainfall was far lower than estimated—due, as already mentioned, to erratic rainfall. The return on the capital outlay had not exceeded 2 per cent. to 3 per cent., and was due to heavy capital outlay on the dam and the absence of a large cultivated area immediately in rear, necessitating a great length of irrigation channels before reaching a suitable soil for irrigation. Besides, in years of drought the tanks were nearly empty, and no revenue would be secured. Within the last ten years the increase of a pure water supply for Ajmere city had to be studied, and good results had been obtained by Mr. D. Joscelyne, Executive Engineer and his successor, Mr. Foy, by damming up the gorges in the adjacent hills. The most satisfactory results, however, had been secured by Colonel S. S. Jacob, C.I.E., State Engineer for the Jeypore State for the last thirty years, who had made a special study of economical tank irrigation. He had covered the district with numerous tanks, following the example of Colonel Dixon (Superintendent of Ajmere and Mhairwara between 1847 and 1857), but on a larger and bolder scale. The most notable work was the Anasagur dam, west of Jeypore city, which crossed the very deep nala with high banks flowing from the Jeypore hills to the north. It was about 1,500 feet long by 60 feet to 70 feet high, with a water slope of about 4 to 1, and consisted entirely of light sandy soil, with a 20-feet roadway on top, and was situated up-stream of the great masonry dam, now in ruins, built by the Rajah of Jeypore about 1865, and which failed when full, owing partly to the water escaping behind the vertical sandy cliffs on which the ends abutted. Colonel Jacob, profiting by this failure, built his dam of the same material as the soil at site, and the ends of the dam were well bonded into the cliffs on each side, and thus any creep of the water around the wings has been stopped. No core-wall or puddle was used in this work. Colonel Jacob was now engaged Mr. Croudace.

Mr. Croudace. on the huge earthen dam and reservoir across the gorge of the Ramgunga nala, where it issues from the hills on the east side of Jeypore, which, when finished, would irrigate some hundred square miles of country. The net revenue derived from his tanks throughout the district varied between 7 per cent. and 12 per cent. on the capital outlay, and the irrigation was entirely under native management. As a rule he built a masonry core-wall, *Fig.* 35, in centre of the dam, with flat water slope, and the down slope was well pitched with stone to avoid damage in the rare case of the dam being topped by flood waters. The waste-weir where practicable was cut out of the solid rock. The rates for work were very low in this district, masonry being built for Rs.15 per hundred cubic feet, say 5*s.* per cubic yard, and earthworks at 1½*d.* to 2*d.* per cubic yard. It should be noted that excessive evaporation coupled with percolation of the storage site would mar

Fig. 35.



Scale, 1 inch = 32 feet.

JACOB TYPE OF DAM, JEYPORE STATE.

many a promising project, and that the site of a reservoir had to be carefully surveyed and contoured before fixing on the position of the dam, which again must be considered with reference to suitable soil for cultivation below the site of dam. Careful experiments on evaporation had been made long ago by Mr. Culcheth, M. Inst. C.E., and Mr. D. Joscelyne, both for a long time Executive Engineers in the Ajmere district, the records of which were buried in Government reports and files. Reservoirs for railways were also of great importance in Rajputana, as the ordinary station wells in many cases contained brackish water, causing great interference to the working of any large traffic. One of the finest reservoir sites in Rajputana was to be found in the desert district of Bikanir, where a catchment basin of some 40 square miles consisted of sheet rock, the flow-off of which passed through a narrow gorge about 100 feet wide. This high level site he had utilized for the Delhi-Karachi (direct) Railway project of 1889–90, for supplying the line with water by gravity through pipes for some 200 miles through the sand hills or "tiba" district. The reservoir was estimated to hold a 5-years' supply, amounting to 70 million cubic feet of water. It was to be built of masonry from 60 feet to 70 feet high, and roofed over with a view of reducing the loss by evaporation. The Bikanir State attempted to dam this stream with a huge masonry wall built of ashlar blocks (set dry) with an earth backing; but it was destroyed by the first flood, and cost this poor desert state a large sum of money. The estimated cost of this covered reservoir of 70 million cubic feet was £233,333 (exchange at 16*d.* per rupee), or at the rate of 1*s.* 9½*d.* per cubic yard of water stored. Mr. Croudace.

Mr. G. O. W. Dunn was entirely in accord with the general principles advocated in the Paper. The subject had engaged the attention of irrigation engineers in Western India for many years past, and the Author had embodied in his Paper, with certain additions and suggestions based on his own practice and observation, the general conclusions which had been arrived at by the Bombay Public Works Department as the result of upwards of twenty years' experience in the construction of earthen dams. The application of the main principles brought forward in the Paper was not confined to India, and to Colonial Engineers especially the Author's remarks should prove of very great value. As a young assistant he had had charge for some time of one of the works mentioned by the Author—the Nehr dam in the Satára district—on which a large number of famine relief labourers were employed in 1876–77. The closure of that dam, however, was done after his transfer elsewhere. He was also connected for a time with the Author on the repair of the Waghad dam, the failures of which (for there were two) had been most instructive, and afforded an example of the saying that there was often more to be learnt from failure than from success; and, in addition, he knew personally all but one of the others of the ten completed works of which details were given in Appendix I., the works numbered 11 and 12 being projected only, and hitherto condemned by the supreme Government. Five of the ten completed dams mentioned had given trouble, owing to slips. Four of these were the first four in point of maximum height, and the fifth was the Ashti dam, the slip of which was, he believed, mainly due to the nature of the foundation, which was of "karal," a soil described by the Author on p. 140 under the head of "foundations." There was no doubt that the material adopted for all these dams, viz., the most retentive "black soil" available, and the system pursued in those Mr. Dunn.

Mr. Dunn. days (for all were constructed many years ago) of very copious watering to each layer, were the chief causes of failure, though in the case of the Waghad dam a great mistake was made in ever attempting an earthen dam at the site, which was eminently suitable for a masonry dam with earthen flanks. The dams which had stood well were: (1) those of moderate height on good foundation, and (2) those which, for want of "black soil," had of necessity to be constructed of lighter soils, less retentive of moisture, as brown, red, or whitish soils. None of the ten dams were drained in construction, and those made of "black soil" and founded on the same, or on "karal," and without any natural drainage in the subsoil, became, with their foundations, like over-wet dough and sank with their own weight, bulging out at the toe on the down-stream side, but kept from doing so on the up-stream side by the superincumbent weight of water. The necessity of providing for the efficient drainage of such works was established beyond question, but he observed that the Author still advocated the use of "black soil," modified, however, by admixture with half its bulk of "murum," or other dry material. He much preferred to reject this rich and exceedingly retentive soil altogether, save only where its use was absolutely necessitated by the absence of other soil within reasonable distance, for experience had shown that a brown soil, or red laterite washdown, or the light-coloured soil locally known as "mán" earth, made an infinitely more satisfactory dam in every way. If "black soil" had to be used it should be mixed with finely broken "murum," when in as dry and powdery a condition as possible, water being added to each layer after consolidation to the absolutely necessary extent only. He agreed with the Author's objections to the use of two trenches, one of puddle and one of concrete, across the river bed, but in recent examples he believed he was correct in saying that this system had not been followed, one central trench only being adopted, the portion across the river bed being filled with concrete and well keyed into the puddle at either bank. He did not think a properly drained dam required the use of berms. The Author acknowledges that the material would be more effectually used to give a flatter rear slope to the dam, and he said that the chief advantage of a berm was to weight the surface of a dam and prevent it bulging, but if made with a sufficient slope and properly drained the dam ought not to bulge, and the sight of a berm on a dam would lead him to the conclusion that the original construction was so faulty that it had been found necessary to weight the toe in this manner. Drains on the face of a dam were most dangerous, and should be altogether avoided. As regards the closure of reservoir embankments, he agreed with the objections put forward to what was described as the "ordinary system," and considered the "new method" to be very decidedly preferable where the conditions admitted. It seemed to be assumed, however, that the bed of the stream to be dammed up was dry, or, at least, carried but an insignificant trickle of water for the seven working months, and this, no doubt, was generally the case in Deccán practice. Were there any constant volume of water to be dealt with, a culvert through the bottom of the dam or through the bank would appear to be necessary in order to enable the dam to be raised safely above the level of the first temporary waste-weir, when the culvert could be permanently closed. The Author's "compound dam" was not likely to be generally adopted in preference to the ordinary type on the score of its additional expense. It was stated in the Paper that "this form of compound dam is only economically feasible where durable stone can be obtained cheaply and abundantly. This is likely to be the case at the sites of gorges which imply the existence of hard materials, and it is for such sites that the type is best suited." When, however, a rocky gorge, where durable stone could be abundantly and cheaply procured, was to be closed, a masonry dam was obviously the proper form to adopt, while for ordinary sites and for dams up to 60 feet or even 70 feet the usual type of earthen dam, with the precautions as to drainage and methods of construction noted in the Paper, was entirely suitable. For greater heights it was probable that the additional cost of a masonry dam would be repaid by the extra security afforded, and by reduced expenditure on maintenance.

Mr. Dunn.

The Author had incidentally mentioned the suitability of large earthen dams as works for the employment of famine labour, and though this question was distinct from the subject of the Paper under discussion, it was one of great interest to the Indian engineer. It might be at once conceded that a large earthen embankment was in itself an ideal famine work. It could afford employment to large numbers of unskilled labourers, men, women, and children, at one place. Being so concentrated, supervision was easy and economical. The labourers could be hutted in properly laid out camps on selected sites in the immediate neighbourhood, and the sanitation and water-supply could be under constant observation. Hospitals and relief kitchens could be established in connection with the work, and satisfactory arrangements made for the necessary supplies of food. Were the object

Mr Dunn. merely to give relief without pauperising the recipients, nothing could be simpler than to raise these enormous heaps of earthwork at convenient centres. But the true policy of famine relief was to employ the labour as far as possible on work that would be of ultimate benefit to the country, either by affording some security against deficient rainfall, or by so improving the means of communication that the effects of a scarcity were reduced to a minimum, or again by reducing recurring charges on existing works for some years to come—as for instance by the collection of stocks of stone metal for road repairs or for railway ballast. The construction of large irrigation works was very frequently urged as the great defence against famine and as the class of work on which famine labour should be mainly employed. Railway earthworks were excellent for the purpose, but it was no use making railways where there was no prospect of even paying working expenses. Roads were useful and fairly suitable works, though they involved the spreading of the labour over long lengths, making efficient supervision difficult and expensive. But a road when made had to be maintained, and if the traffic was only likely to be small the result was an unnecessary burden on the Local Board or on provincial resources. In the case of irrigation works regard must be had to the conditions obtaining, and, as far as Western India was concerned, experience so far had shown that the construction of storage reservoirs, though affording the best possible work for the employment of famine labour, was the most extravagant form possible. In the famine of 1876–77, when there was a "boom" in irrigation in the Deccán, a very large portion of the relief labour was employed on earthen dams for storage reservoirs, and when the famine that had just closed was threatening, he had occasion to take out some figures relative to those works. He found that for every rupee spent on them during the famine, two rupees had to be spent afterwards to complete the works and bring them into operation, and that the result after all had been a considerable nett annual loss to the Government. The cause for this was not far to seek. That considerable expenditure was necessary over and above the earthwork of the dam was obvious, and that annual charges for establishment and maintenance would be involved was of course foreseen. Where the failure had been was in the small advantage that was taken of the means of irrigation provided, and in the fact that when the water was wanted most, owing to failure of rain, it was not to be had. A closer study of the circumstances should have convinced the projectors of these works that this must be so. It was stated at the commencement of the Paper that (in Western

India) irrigation reservoirs might be divided into two classes, (*a*) 'Ghaut-fed,' with an assured annual replenishment, and (*b*) Eastern, with an uncertain annual replenishment. In the Western districts, with the assured annual rainfall, there was no necessity for irrigation or for relief works. Where they were required was in the Eastern districts—in what was known as the "famine zone"—where the rainfall was capricious. As the reservoirs, equally with the crops, depended upon the rainfall, the supply to them was deficient just when the crops most required them. Again, the volcanic formation of the Deccán was very different from the alluvial plains of the Punjab and Northern India. There were no large perennial rivers fed from Himalayan snows and charged with fertilizing silt. The Deccán watercourse, or "nullah," was a roaring torrent after heavy rain, but was dry, or nearly so, for the greater part of the year. The country was a succession of barren ridges and of valleys, which were, as a rule, very rich and fertile. The black soil, of which these valleys are chiefly composed, wanted only moderate rain to produce luxuriant crops, and sufficient was generally forthcoming. There was, therefore, no inducement to irrigate anything but garden crops which required a good deal of capital, for the land must be levelled and the clear reservoir water necessitated heavy manuring. Those farmers who could afford to grow such crops were not those who suffered when a scarcity occurred. It was the vast numbers of the poorer occupiers, the labourers, and the artizans who had to be cared for; and, as far as they were concerned, the existence of the Deccán reservoirs had no appreciable effect. It would thus be understood that, excellent as such works were in themselves for the employment of famine relief labourers, the construction of earthen dams for irrigation reservoirs was not likely to be undertaken for the purpose, save in exceptionally favourable cases, until all other useful and suitable classes of work were exhausted; and then it was highly probable that, on the cessation of relief measures, the unfinished heaps of earth would be allowed to remain untouched until the next similar calamity afforded an opportunity of going on with them. The whole question of the suitable employment of relief labourers was extremely difficult, and his remarks might be regarded as an answer, from the particular part of India in question, to those who would advocate indiscriminately the further extension of irrigation as the great remedy for the evils of an uncertain rainfall. Mr. Dunn.

Mr. W. Fox desired to take exception to the Author's statement that engineers as a rule viewed the construction of dams Mr. Fox.

Mr. Fox. of more than 60 feet in height with distrust. There were innumerable instances of such constructions in England, and, were the limit placed at 60 feet, very many reservoirs with embankments of from 80 feet upwards, if reduced, would not be worth making, as the capacity obtained with the lower height would be so small. He had investigated two instances where he found that the difference between 60 feet and 80 feet in the height of the embankment added 100 per cent. to 150 per cent. to the capacity of the reservoir without increasing the cost in anything like the same ratio. Nor could he agree with the Author's statement that, "notwithstanding all precautions, some water would certainly pass through the puddle." Should such be discovered, it would, in his opinion, be a source of very grave anxiety. No doubt it was not uncommon for water to pass round the ends of the puddle-trench or underneath, if the foundation rock was stratified; but so long as the water issuing was clear it was of no consequence; and his experience was that such leakages gradually decreased. He considered it unnecessary to make the puddle-trench as wide as 14 feet; and with regard to the suggestion by the Author that a longitudinal dry-stone drain 4 feet by 3 feet should be placed in the bottom of the trench, he would draw attention to the unnecessary width of trench caused thereby. Moreover, he thought the very last place for laying a drain should be along the bottom of the puddle-trench, although at times it was necessary to bring up vertical stand-pipes to relieve the trench of any springs which might be found, and he had on one or two occasions surrounded the bottom of the stand-pipe with a small quantity of dry rubble stone. Round this, however, he invariably placed the very best concrete that could be made. He sometimes continued these vertical pipes to the drain underneath the outer part of the embankment; but if the water should cease to rise in them below the surface of the ground he filled them with cement grout and left them. With regard to the proper slopes to be adopted, he considered that no hard-and-fast rule could be laid down, although he considered the suggestion shown on Fig. 8—viz., to flatten the slopes as the height increased—a good one. Everything, however, must depend upon the material at hand. With dry stony material, he had constructed an embankment, with an outer slope of 2 to 1, nearly 100 feet in height with perfect success. On the other hand, with rich clay he had found it impossible to get this slope to stand even at 20 feet to 25 feet. With such material, he had successfully adopted the suggestion shown on Fig. 8, of constructing the inner

Mr. Fox. and outer toes of dry stone or burnt ballast, the latter having been used where a large quantity of lias and oolitic silt had to be got rid of. Instead of running it to spoil, it was burned *in situ* in the toes of the embankments, and it was found that after this had become saturated with water it had set hard and become practically a mass of concrete. It so happened that in this instance a quantity of town refuse was obtainable, which took the place of small coal or breeze, and the cost of the work was much less than it would have been had the material been run to spoil and the toes made with dry rubble. The question of a proper amount of moisture to be used in the formation of an embankment in England he had never heard fully discussed. In his own opinion, although he had recently known as much as 4 inches of rainfall in twenty-four hours, which rendered an embankment in progress so wet that work could not be resumed for some days, he believed that, so long as it did not cause the slopes to slip, it was impossible to use too much water, as it helped consolidation. And in the preparation of the puddle, it was his practice to use much more water than was apparently used in Western India, for it would be impossible in any puddle-trench or puddle-wall which he had constructed to put a heavy roller upon it. He also doubted the advisability of rolling each layer, as it had a tendency to form horizontal planes corresponding to straight joints in brickwork or masonry, which facilitated the passage of water. He much preferred cutting the puddle with long grafting tools 12 inches to 16 inches in length, and afterwards treading it—by which means one layer was thoroughly incorporated and bonded into the one below it. The quantity of water used must depend upon the tenacity of the clay; but he aimed at making the puddle so soft that it would only just bear the weight of a man when treading it. He did not see the use of making the whole of the inside of the embankment impervious to water, because, however well this might be done, the material underneath the base of this part of the embankment was, at any rate in England, more or less open and porous, especially in the bed of the stream; and thus, although the embankment might be watertight, water would find its way underneath the embankment up to the puddle-trench, which must always be the key to the success of the whole structure.

Mr. Gravell. Mr. DAVID GRAVELL remarked that one of the most notable differences between the construction of earthwork dams in Bombay and in the United Kingdom was as regards the use of puddle-walls, which the Author mentioned as never there occurring in

Mr. Gravell. the dams themselves, the puddle being confined to the foundation trench, as distinguished from the almost universal practice here of carrying up the puddle-wall to or near the top of the dam. To reconcile this important difference in practice, presumably the "black cotton" soil must be regarded as puddle, and therefore might be used equally well in the puddle-trench, especially as there, being confined, its tendency to slip would be of little importance. The depth of the puddle-trenches was also much less than was generally found to be necessary in England, so that the geological conditions of Bombay might be considered as more favourable for dam construction. It appeared that in Bombay it was usual to form the outlet by a culvert through the natural ground under the dam, and this being so the Author's recommendations for ensuring a solid foundation throughout the length of the culvert by a wide concrete foundation, &c., were of great importance, especially as regards the crossing of the puddle-trench and the use of concrete to the full depth of the trench in place of puddle, where the culvert crosses. The Author stated his objections to the adoption of the outlet formed by tunnelling in the hill-side clear of the dam, and although admitting that, being quite independent of the dam, it could not cause damage, on the other hand, stated that it was very expensive, and, being underground, difficult of supervision. This was the more likely to be the case in a country such as Bombay, where skilled labour of the particular kind might be difficult to obtain, but in England it was becoming generally recognised that wherever practicable this form of outlet was far preferable to the old method of culvert laid through or under the base of the dam. An instance of the early type of earthwork dam for a reservoir was the Glencorse,[1] for the Edinburgh supply, designed by Telford, and although the thickness of the puddle-wall was about twice that now adopted here in general practice, the slope of 3 to 1 on the inner side was still almost universally adhered to, but for the outer slope was steepened to $2\frac{1}{2}$ to 1,[2] and in some instances 2 to 1,[3] the latter being also that of the type adopted in Western India.

Mr. Herschel. Mr. Clemens Herschel remarked that there was probably no greater contrast than that between the methods of construction of similar engineering works in India and in the United States. In the one, native labour, not infrequently pauper labour, and

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[1] Minutes of Proceedings Inst. C.E., vol. lxxiv. p. 91.

[2] *Ibid*, vol. lxxiv. p. 91.

[3] "Engineering," Institution of Mechanical Engineers, vol. xlvi. p. 465.

including women and children, did the bulk of the work, by semi- Mr. Herschel. civilized methods, for a few cents daily wages; in the other, native labour scorning to do any such work, but allowing sturdy male immigrants to grow rich in their own estimation in one working season, by doing it with the aid of superior labour-saving machinery. And yet the forces to be overcome were the same in the two places, and earth that would puddle in India would do the same in the United States. The difference was one of social conditions and of kinds of civilization, and if an engineer wished to achieve a maximum of success, he must always take cognizance of such differences and of the habits and abilities no less than the prejudices of the labouring people of the different countries in which he might be called upon to do work. Differences between Indian earth dams and American earth dams there would always be; but some changes in the design of Indian earth-work dams might suggest themselves to Indian engineers from the consideration of American methods. His view of the essentials of an earth-work dam was a structure, composed of an unstable watertight curtain fastened across the watertight surface of a valley, extending up to a horizontal line and held up or supported on each side by an earth fill. The slopes of the earth fill must be protected, on the one side against wave action, on both sides and on top against the destructive effects of rain. There must be a waste-way able to discharge a flood, the greatest known, or to be expected, flood, without raising the water higher than flood-level in the reservoir, and there must be a way provided to draw off the water as wanted. Before discussing how this programme was to be embodied in earth, stone and metal, he would define some of the terms he would use. Clay was sticky, treacherous and mud-producing. It encumbered the site of the works, and he had never found a use for it, except to make clay-rolls for pouring lead-joints, in an experience on hydraulic works, during the past 35 years. When present on the ground, it must be endured, but he had never allowed it to be brought to the site of the works. Gravel was a natural mixture of earth, sand and pebbles; of various attributes and consistencies; some of which was good for building earth dams, and some not. The best for that purpose was gravel that would puddle, or "binding gravel." To tell whether any given gravel would puddle, and to judge of its fitness for use in a dam, it should be mixed with water in a pail, to the consistency of moist earth about to be used in a dam, or before rolling. If, on turning the pail upside down, the gravel remained in the pail, it was fit for use; but if it dropped out, Mr. Herschel. it should be discarded. Good gravel, or binding gravel, would make the best of coffer-dams, or filling for sand-bags to be used in coffer-dam work, and earth dams. It would remain water-tight, where clay would melt out and disappear like soap or sugar. Good earth or gravel, stone and metal parts being provided, the method he advocated for the construction of an earth dam was the following. The site should be cleared of perishable material, and a trench dug down to waterproof strata. If good rock was found within 25 feet, or 30 feet, or 35 feet, a start should be made upon it, but if not, excavation should proceed with some sort of stop-water until there was no danger of water passing out from the reservoir down the valley, in quantity underneath the bottom of the trench. This was a matter of judgment. A concrete or masonry core-wall should be constructed in this trench, say 4 feet or 5 feet thick at the bottom, 8 feet thick at the original ground level, 4 feet thick at the top. These were dimensions for first-class work; but such core-walls had been built, only 2 feet thick uniformly from top to bottom. At the same time with it should be built up the earth dam on each side of it, using for the earth dam good binding gravel, hauled on and spread in 4-inch or 6-inch horizontal layers. These should be sprinkled with a hose constantly, and rolled with grooved rollers plentifully, and until a hole dug in the gravel would hold water like a pail. The grooved rollers were made of disks of cast iron strung on an axis, the alternate disks being of the same diameter; and contiguous disks, about 2 inches smaller and larger in diameter than their neighbours. Such rollers could be turned easily, and their total weight was concentrated on an aggregate bearing surface equal to only half the length of the whole roller, and therefore more effective where it rolled than if the whole length touched the earth. The reference to these rollers on p. 147 misapprehended their function and object. Slopes of 2 on 1 were sufficient for both sides of the dam; 1½ as well as 2½ have been used. Berms were advantageous during construction, as level track-ways, from one side of the valley to the other; but their use was a matter of fancy, largely. He favoured them and had always used them for earth dams over 40 feet high. A gravel walk should be made on the top of the dam, and a vacant strip left on each side of it, to the edges of the dam. These top strips and the berms should be sown with grass. The back or down-stream slopes might be sown, or sodded, or covered with a layer about 2 feet thick, of small (8 inches or 9 inches in diameter) stone culled out of the gravel filling while building the dam. The waterside was paved. He had used with success large

Mr. Herschel.

boulders from the borrow pits with smaller boulders and small stone in the interstices. To draw off the water he had used the "dry-well" method. Near one end of the dam, a ditch was excavated at right angles to the core-wall trench, and at the elevation of the bottom of the reservoir. At the crossing of the two trenches was placed the dry-well, a square tower or chimney having one, two or more divisions in plan, and built up as the dam was built up. Culverts led to it both up-stream and downstream, and through it run two, four or more cast-iron pipes. Ordinary stop-valves were set in line of these pipes, two stop-valves "in series" in each line of pipe. One of these valves, the downstream one, was for use, the other for the event of repair of the downstream valve being necessary. The wasteway was a separate structure. Nothing but a smooth stone weir, of length sufficient to pass the maximum flood without unduly raising the reservoir water-level, seemed a safe arrangement. This type of safety-valve would not get out of order. The earth-dam was safe against the attacks of vermin; they could not penetrate the core-wall. The core-wall was a safe stop-water to rely upon, whether of masonry or concrete. It would not crack like clay-puddle. If it should crack, by faults of construction, the crack would not enlarge, should water reach it. It would be more likely to silt up. Drains under the dam were uncalled for. A dam of this kind had never indulged in such slips and slides as were portrayed in the Paper. Such slipping could only be caused by a lack of staunchness of the whole structure. Water must have penetrated the body of the dam, and have come dangerously near to carrying away the whole of it. A core-wall dam could be built in less than one summer season, and the reservoir filled with water the following winter. The main earth-dam of the Canistear Reservoir of the East Jersey Water Company of New Jersey, U.S.A., was about 57 feet high from the original surface of the ground to the top, and about 672 feet long on top. The water area of the reservoir when full was 323 acres; contents, 2,407 million United States gallons (at 231 cubic inches). The wasteway was 275 feet long, to provide for the floods, possibly, of 10·5 square miles of drainage area.

A Lidgerwood cableway was used to build the core-wall; steam pumps, two tanks, and lines of piping furnished the water for sprinkling and to the steam-driven concrete mixer; carts, and wagons, and rollers in number, to fairly crowd each other off the top of the filling, were at work while building the earth dam; steam hoisting-engines handled the derricks; and an electric light plant furnished the light for night-work. In this way, a dense

Mr. Herschel. forest, on the site of the dam on June 10th, 1896, gave place to the practically completed dam by November 1st following, that was, 5 months later, when the gates were closed, and the water was allowed to fill the reservoir. The reservoir had been full since August, 1897. He had built two such reservoirs, a masonry intake dam across the Pequannock River, three gate-houses, and a lot of bridges and culverts, by day labour, also 26 miles of steel conduit by contract, in the two working seasons of 1890 and 1891. These works had been in use since the 1st May, 1892. To build the Canistear Reservoir in 5 months cost about £9,000 more than it would have cost to build it in two seasons.

The bill of quantities of work is as follows :—

Main dam and reservoir, clearing	440 acres.
„ „ grubbing . . .	440 „
Excavation on dam-site	11,000 cubic yards.
Gate-house cut, rock	1,200 „ „
„ „ earth	5,700 „ „
Core-wall excavation, rock	2,450 „ „
„ „ earth	2,100 „ „
„ „ concrete	8,000 „ „
Dam, earth, including paving	98,000 „ „
Gate-house masonry, brick	100 „ „
„ „ stone	1,500 „ „
„ „ concrete	150 „ „
„ fittings, pipes, valves, stairway, &c. . . .	
New road	11,562 feet.
Overflow dam, excavation, earth	2,700 cubic yards.
„ „ rock	1,450 „ „
Masonry	4,500 „ „

Auxiliary Dam No. 1.

Clearing site of dam	850 „ „
Excavation for core-wall, rock	80 „ „
„ „ earth	150 „ „
Core-wall, concrete	300 „ „
Earth dam, including paving	1,400 „ „

Auxiliary Dam No. 2.

Clearing site of dam	950 „ „
Excavation for core-wall, rock	20 „ „
„ „ earth	600 „ „
Core-wall, concrete	750 „ „
Earth dam, including paving	2,450 „ „

Mr. Hopkinson. Mr. John Hopkinson remarked that, in England, where the average rainfall of the wettest month in the year did not exceed

Mr. Hopkinson.

twice the average of the driest, the difficulties to be contended with in collecting, storing, and distributing water in India, whether for irrigation or for the supply of towns, could scarcely be appreciated. A general statement was given in the Paper as to which months in the year, in the Bombay Presidency, had a heavy and which had a small rainfall or none at all, and also a few instances of heavy falls of rain in short periods, a day or less, but the average monthly fall at Bombay, and the extreme deviations from the average, might also be of interest. The monthly rainfall at various places in the British Empire had been given in a series of Tables in "The Colonies" and "The Colonies and India," from 1874 to 1881, and from that date onwards in "Symons' Monthly Meteorological Magazine," the record for the 23 years, 1874 to 1896, being complete. The means for this period showed that the months of heaviest rainfall at Bombay were June to September, not July to October, as stated by the Author to be the case generally in the Bombay Presidency. The mean monthly fall for the 23 years was as follows, the year being purposely divided into three periods of four months each, commencing with February.

—	Inches.	Days.	—	Inches.	Days.	—	Inches.	Days.
February .	0·04	0	June . .	20·12	21	October .	2·29	5
March . .	0·02	0	July . .	26·36	29	November .	0·49	2
April . .	0·01	0	August .	14·24	27	December .	0·06	0
May . .	0·63	2	September	11·67	20	January .	0·13	1
	0·70	2		72·39	97		2·97	8

Of the mean annual rainfall of 76·06 inches on 107 days, less than 5 per cent. thus fell on only 10 days in the 8 months October to May, and more than 95 per cent. on 97 days in the 4 months June to September.

The maximum monthly falls were:—

—	Inches.	Days.	—	Inches.	Days.	—	Inches.	Days.
February .	0·51	3	June . .	43·45	28	October .	10·40	13
March . .	0·21	3	July . .	47·64	31	November .	2·63	7
April . .	0·08	2	August .	36·56	31	December .	1·14	3
May . .	6·30	9	September	22·80	26	January .	1·85	4

Mr. Hopkinson. The minimum monthly falls were:—

—	Inches.	Days.	—	Inches.	Days.	—	Inches.	Days.
February .	0·00	0	June . .	5·11	14	October .	0·00	0
March . .	0·00	0	July . .	10·75	25	November .	0·00	0
April . .	0·00	0	August .	4·08	19	December .	0·00	0
May . .	0·00	0	September	1·62	9	January .	0·00	0

While 8 months in the year had been absolutely rainless, rain fell every day in July in 6 years out of the 23 years, and every day in August in 3 years. In questions relating to water-supply and storage, it is perhaps of most importance to note the wettest and driest periods, especially the latter. The wettest period was from June to September, 1878, when 105·05 inches fell, being $26\frac{1}{4}$ inches per month for 4 months; the next was from June to September, 1896, when 96·47 inches fell, 79·34 inches of this amount falling in June and July; and the next was from June to September, 1874, when 82·11 inches fell. Provision should therefore be made in Bombay to dispose of a fall of at least 100 inches in 4 months, and of 80 inches in 2 months, and in some places in the Presidency the fall doubtless greatly exceeded these amounts. The longest period without any rain was between October, 1875, and April, 1876, while only 0·01 inch fell in May, on 1 day, so that, practically, there had been 8 consecutive months without rain; there was no rain from November, 1891, to April, 1892, inclusive; and twice there had been only 0·01 inch in these 6 months. Thus it was necessary to have sufficient storage-capacity for an 8-months' supply, while it should be anticipated that a 6-months' supply might frequently be required. With regard to variation in the annual rainfall, there was not nearly so much falling off in the driest year as there was an excessive fall in the wettest; the smallest fall in any year was 57·82 inches in 1888, and the greatest, 111·93 inches in 1878.

Mr. Hutton. Mr. W. R. Hutton thought the methods of the Author were sound, and showed great care and intelligence in the construction of his works. Some of his details seemed unnecessary, and in a few points undesirable or dangerous. Methods of construction of earthen dams were largely matters of the materials at hand. There had been recently, however, much discussion upon materials and much difference of opinion. All the clays come from the decomposition of the feldspathic or other crystalline rocks. The

Mr. Hutton.

purest, kaolin, was composed of alumina, silica, and water, and the smaller the proportion of silica the more water would it absorb and retain. Common clays were composed of finely-powdered feldspar, quartz, and other minerals, and often more or less kaolinite. They always contained sand or other impurities. The materials, therefore, which were classed as clays differed greatly in character. Some of them were utterly unfit for hydraulic works; some were so soft as to be called quicksands. To this variation of character might be attributed the various opinions upon the value of clay in embankments. The same might be said of the gravels or gravelly earths. Those which contained no binding material were not suitable for embankments to hold water. Mixed with clay in suitable proportions good results were obtained. It would seem from the description that the black cotton soil, watertight, could be made a very suitable material for reservoir banks by the admixture of a considerable proportion of murum, which was decomposed trap, heavy, hard, and friable. It would doubtless prevent cracking and slips, which were the consequences of using the cotton soil unmixed. The puddle trench and the puddle wall of the older American engineers, which had done most satisfactory work, had been to a great extent superseded in the northern parts of the United States by the core-wall of concrete or other masonry, and the soft puddle formerly used was replaced by a material made with much less water that it might be compacted by means of the grooved roller. Doubtless the soft material would settle more than the drier mass, and as it settled would pack more solidly into the sloped sides of the trench. The puddle wall was continued through the embankment to high-water line. It was the chief dependence to prevent percolation. The core-wall of later days was intended to take its place. It was carried down to an impermeable stratum, and was built with a batter in the centre of the bank to near its top. To be of use the core-wall must be thoroughly well built. It was his own practice, where a core-wall was used, to plaster smooth the battered sides and place against them a certain thickness of soft puddle, which in settling was packed firmly against the wall. The same method was followed wherever embankment was in contact with masonry. The latter was built with a smooth batter, and soft puddle was interposed between it and the rest of the embankment. This method had been in use for 50 years on the Chesapeake and Ohio Canal with the best results. It was recommended by Graeff in his memoir on the canal from the Marne to the Rhine, and had been found uniformly

S 2

Mr. Hutton. successful in his practice. The Author attached, perhaps, too much importance to the filtration through and under the bank. If the front part of the bank was made of good material, well connected with the solid ground on which it rested, but little water could pass the puddle wall or the core-wall, and that little was absorbed by the material of the outer slope. Every effort should be made to prevent filtration, which, little by little, would carry away the material from the outer slope, cause slips, and, if neglected, more serious damage. Cases had occurred in which a spring had been discovered after the base of the embankment had been prepared. When this occurred it must be carefully covered, and the water carried off by a drain, but it was always a source of danger. On the other hand, embankments to hold water were sometimes built from necessity of a material which could not be made watertight. In such case the heavy puddle or core-wall aided by puddle was depended on to stop the water, the slopes being merely the supporters of the stop-water; but if the subsoil water or water from the reservoir escaped through seams in the underlying rock, it did no harm to the reservoir, and was, moreover, very difficult to prevent. The small trenches shown on *Fig. 9* are useful to prevent filtration between the natural earth and the embankment. They might be continued at the ends, but a single puddle trench carried well into the hill and carefully filled should be ample to prevent filtrations. The ground sloping transversely to the axis of the dam was always cut into horizontal benches with, not vertical, but sloping faces. Slopes in the direction of the axis were better left alone. The earth rarely slipped upon the natural surface; if it did it consolidated the bank. Formerly the earth was spread in 6-inch layers and consolidated by the carts. The grooved roller now did the work with greater efficiency. The water-slope of the dam was protected by "pitching" rarely less than 12 inches deep, laid upon 6 inches of gravel. The latter was an effective protection against any "vermin" found in America. The more frequent practice was to lay this work in cement. The closure of a dam or a stream whose discharge was greater than could be carried off through a practicable culvert or bye-pass must be made with masonry, which would probably be used as the waste weir. The outlet culvert could be made perfectly safe by good workmanship, ample material, and numerous cross walls around it to prevent water following its straight lines; the circular form was preferred. No objection could be made to cast-iron pipes if bedded in and covered with good concrete, with cross walls at intervals over and around the concrete as in the culvert.

Mr. Hutton.

The valve-tower was placed at the foot of the water-slope. In one case an iron pipe 4 feet in diameter to which the gate was attached was built into the wall. The pipe was continued a short distance under the embankment, and was joined to the 6-foot culvert by a cone of brickwork. For ordinary purposes a sliding gate was sufficient; where the opening was large and the head considerable, the form of gate proposed by Mr. Fontaine, Engineer of Ponts et Chaussées, was to be preferred.[1]

In his conclusion the Author again referred to the drainage of the embankment, taking every precaution to prevent filtration up to the centre line, while beyond it every facility should be afforded for the escape of the water. If there were a puddle wall or a core-wall the motive would be apparent, but he did not see why an arbitrary line should be drawn at the centre of the bank up to which it should be made as tight as possible. Why should it not be drawn at the foot of the outer slopes?

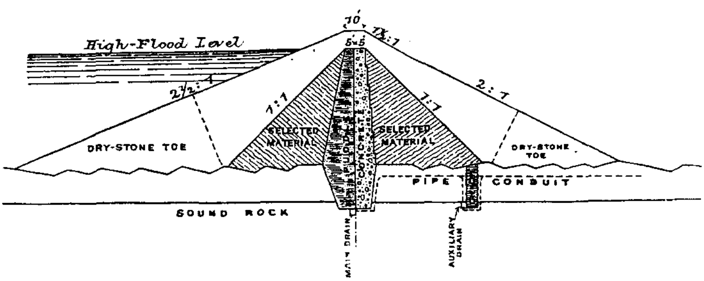
Mr. Kreuter.

Mr. F. Kreuter, of Munich, thought that, in view of the dreadful disasters which, as a rule, arose from the failures of reservoir dams, safety was the factor of primary importance. High dams should, therefore, not be constructed where the ground was of a treacherous description. When, however, a water-proof stratum could be reached by the trench, then the core-wall or hearting should be made thus as to join best with that stratum. According to a well-known rule, therefore, masonry or concrete cores were recommended, when the impervious strata were rock, and puddle-cores when it was clay. The measures to be taken in favour of safety should be improved as the height of the dam was increased. Since, however, the volume of the dam grew at a very high rate with its height, the additional expenses for more perfect precautions would be found to be relatively small in proportion to the volume. He agreed with the Author that, "It is better to prevent slips at some extreme outlay than to run the risk for the sake of a comparatively small original economy." He was somewhat diffident of the safety of high earthen dams constructed after Indian practice. The Author himself stated, on p. 166, that "Although Indian dams are carefully constructed, still slips occur." It would, therefore, seem that, for high earthen dams only a system of construction, similar to those peculiar to England and America, should be used. The Author apprehended that unfavourable internal stresses might arise from the use of different materials. He thought it would be, on the contrary, advantageous

[1] Annales des Ponts et Chaussées, 1886, vol. xii. p. 254, plates 32, 33.

Mr. Kreuter. to compose the dam of certain portions, each of which had to serve for a definite purpose, provided that every portion was so arranged as to be allowed to settle without injuring the others or getting in disorder itself. The large plane-joints in which those portions abutted against each other, and which broke the layers in which the several portions had been built, seemed to be favourable to impermeability. This latter important quality was, as experience taught, never attained by the more or less perfectly stratified structure of Indian dams, and the danger of being percolated and soaked increased with the head of water. He would, therefore, in the case represented in *Fig. 9*, prefer a dam with core-wall of concrete, as in the dams of the Boston waterworks, the construction of which he had fully described.[1] As no concrete core, and indeed no masonry was perfectly waterproof in itself, it might be protected and made tight by lining it inside with

Fig. 36.



clay puddle. The core-wall then really consisted of two portions, a rigid one and a plastic but waterproof one. This was shown in *Fig. 36*, for which he had adopted the principal dimensions as given in *Fig. 9*. The remainder of the cross-section corresponds to the well-known constructions. The down-stream half of the dam was kept perfectly free from percolation, and would act as a safe buttress. The Author's method of applying drystone toes was certainly a very sound one; only it might probably not be necessary to make the layers so very steep. Slightly-curved layers, concave above, steep at the slope and flat behind, had been employed in constructing the huge drystone toes of large embankments of the railway across the Brenner, and had answered well. They might do just as good service here. He desired to add a

[1] Zeitschrift des Vereines deutscher Ingenieure, 1895, p. 1219 *et seq.*

Mr. Kreuter.

few words as to the drainage of the base of dam. Slipping must not only be prevented within the mass of the dam, for it might also occur along any surface within the permeable material between the base of the dam and the surface of the rock, inasmuch the more as the latter was frequently covered with a thin layer of wet clay, as slippery as soap. Now, when a surface was liable to become slippery by the access of water, it was obviously of no use to catch the water where it left the slippery surface after it had been running across it. Nevertheless this was in most cases done. The water could only be prevented from rendering such a surface slippery when it was cut off by a drain, before it reached the surface in question. This was the only way of withdrawing the tendency of slipping by simply keeping the proper surface dry. With a view to this fact he had designed a system of drainage (*Fig. 36*) somewhat different from that of the Author. The small drains at the base of the dam, as shown in *Fig. 9*, would not prevent a slipping at some surface between the base of the dam and the surface of the rock, and, moreover, the water had to pass below the whole foundation of the puddle hearting in order to reach the drain. In *Fig. 36* the water was cut off by the main drain running along the axis of the dam before it could reach the base of the concrete wall, and it was then discharged through the pipe conduit. Thus the surface downstream from it, together with the whole stratum of permeable material above it, would be kept as dry as possible. For the sake of safety, he had proposed a second "auxiliary drain" at the toe of the slope of "selected material," parallel to the former, which, together with the puddle-wall W, would certainly keep the whole basing downstream from B dry, so that no slip could arise. The discharge-pipe, or conduit, would be best laid upon the surface of the rock. Should this, however, be too deep, the pipe might be lifted nearer to the ground-surface. By the head required to raise the water in this case, a tendency towards percolation was produced. But since the resistance to percolation into the compressed earth was much greater than that to flowing through the pipe, no sensible soaking was to be effected.

Mr. Marten.

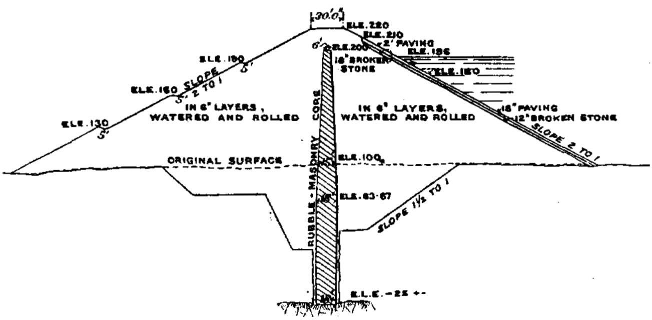
Mr. E. D. Marten was particularly interested by the account given in the Paper of the enormous floods which had to be dealt with. At the Jamba weir, as stated in Appendix II, a flood was recorded amounting to 373,000 cubic feet per second from a catchment area of 2,050 square miles. This was about the same as the catchment area of the Severn above Worcester, where a bankful flood was only at the rate of about 10,000 cubic feet per second, Mr. Marten. and where the great flood of May, 1886, was calculated to have attained a volume of about 40,000 cubic feet per second. This was the greatest recorded flood at Worcester, and yet its volume was less than one-ninth of that from an equal catchment area on the Jamba. Again, the run off from catchment areas was many times greater than that which had to be dealt with in England. Since the completion of the Vyrnwy dam in 1888, he had received, in his capacity of Engineer to the Severn Commissioners, daily information from their water-bailiff as to the height of the water above or below the crest of that dam, and in the years immediately following 1888, when but little water was being abstracted for Liverpool, he had good opportunities of observing the maximum discharge from the catchment area. The greatest recorded flow was on the 10th December, 1891, when the water discharged into the Severn from Lake Vyrnwy passed over the 456 feet of waste-weir, which was formed by the crest of the dam, with a depth of 1·7 foot, equivalent to a discharge of 215,000 cubic feet per minute, or over 13,000,000 cubic feet per hour. The catchment area was 18,000 acres, so that the discharge was equivalent to a run-off of about $\frac{1}{5}$ inch per hour over the catchment area, and yet, in India, for catchment areas of similar size, it was found necessary to provide for a run-off of 1 inch, or five times as great. The Vyrnwy flood referred to must have been very nearly a maximum flood from the catchment area. The rainfall of the preceding twenty-four hours had been 2·7 inches, and there had been about $\frac{1}{2}$ inch on each of the four preceding days. Moreover, the reservoir had been full and overflowing 5 inches or 6 inches deep for a week previously, so that all conditions were favourable for an extreme discharge. Apparently, therefore, somewhere between four and five times more waste-weir provision would be required in India than in even so wet a district as Lake Vyrnwy. In the early part of the Paper, under heading "Concrete and Puddle-trenches," the Author remarked that, in England, puddle was relied upon to make the concrete beds and walls of service reservoirs watertight. He believed that this was altogether at variance with modern practice and with the necessities of the case. He had recently constructed three service reservoirs of cement concrete without using any puddle, and they were all perfectly watertight, and he was aware of several similar instances. The use of puddle in connection with service reservoirs was objectionable. To be effective, the reservoir must be enclosed on bottom and sides by an unbroken skin of puddle, and this frequently led to subsidences in the floor of the reservoir. To guard against such subsidences, some engineers had carried footings down through the puddle to the solid ground below it, thus breaking the continuity of the puddle casing, and to all intents and purposes rendering the puddle useless. Mr. Marten.

Mr. L. F. VERNON-HARCOURT observed that the Western Ghauts, like all mountain ranges near the sea, arrested the moisture brought from the ocean, so that though there was an abundant rainfall on their slopes, there was a great scarcity of rain in the district, to the east of them further inland. This interception of the rainfall by mountain ranges had proved a serious hindrance to agriculture in the country lying to the east of the Rocky Mountains in North America, and was specially prejudicial in the torrid climate of India, where, moreover, the value of the crops was enhanced by the abundant population and deficiencies in means of communication. The great outflow from the Ghauts during the rainy season was indicated by the deep gorges which intersected their slopes; and the storage of some of this abundant supply was an inestimable benefit for mitigating famines, by its distribution over the parched lands during periods of drought. The reservoirs referred to by the Author had been closed by earthen dams of moderate height; and he advocated the use of those dams for greater heights, with the adoption of special precautions in their construction, in preference to masonry dams. Undoubtedly the cheapness of earthwork in India, and the possibility of utilizing it for famine relief works, as well as the solidity obtained by the basket-work employed by the natives, rendered earthen dams specially suitable for closing reservoirs of moderate depth in somewhat wide valleys; but there must be some sites in the Bombay Presidency where, with rock foundations in a narrow valley, a deep reservoir could be more conveniently and safely formed by a high masonry dam; and the reservoir could be effectually secured from silting up by scouring sluices through the dam near the bottom of the reservoir. Moreover, in the cases where slips occurred, their repair would very materially detract from the apparent economy of earthen dams. Theoretically it would be advantageous to construct a watertight lining on the upstream slope of an earthen dam; but with the variations in water-level and temperature, irrespectively of any settlement, this was not practicable, as a lining of clay or concrete was sure to crack; and the divergence of Indian practice from that in England, in using a large mass of more or less impermeable material in the upstream portion of the dam, seemed to be due to the absence of suitable materials for puddle, rather than to any real objections to the adoption of a central puddle wall. The Mr. Vernon-Harcourt.

Mr. Vernon-Harcourt. ordinary method of closing earthen dams in India, by rapidly filling up a central wedge from the bottom to the top in the highest part of the dam, was clearly objectionable, as tending to produce unequal settlement and cracks in the central portion of the dam; and the raising of the dam right across in layers, as advocated by the Author, with provision for a temporary waste-weir at the side, was manifestly the proper course. Slips appeared to be not very uncommon on the downstream slope of the dam; but the Author had stated that no slips had occurred on the upper slope of any of the large Bombay earthen dams, showing that ample stability had been secured on the upstream slope. This stability might be attributed to the protection afforded from the sun by the pitching or concrete layer, and its weight, when the water was low in the reservoir, and also the protection of the earthwork from the rains, and the support of the water in the reservoir during the rainy season. The slips on the downstream slope of the dams, besides being aided by the downward slope of the valley, might be caused by the infiltration of the rains into the mass of the dam through the cracks formed by the heat of the sun in the dry season, as in deep railway cuttings through clay, even in the absence of any percolation from the reservoir; and the remedies against such slips were thorough drainage of the mass near its base, and a flattening of the downstream slope, especially towards the base. The stepped waste-weir, proposed by the Author, would have the advantages of affording a more thorough control of the outflow, and enabling the reservoirs to be safely maintained at a higher level. The beneficial action, however, of this type of weir claimed by the Author, of discharging the first floods heavily laden with silt, could only be very partially realised, considering the height of the proposed sluices of the weir above the bottom of the reservoir, as the flood-waters entering the upper end of the reservoir would deposit a considerable portion of their burden of silt in mingling with the water in the reservoir below the level of the sill of the sluices, before being discharged through the sluices.

Mr. Wegmann. Mr. EDWARD WEGMANN thought it would be generally agreed that the design of an earthen dam was to be based more on the results obtained by experience than on theoretical principles. The climate of the country, the storms to which the dam might be exposed, the best materials available for the construction at a reasonable cost, were points that must be considered in designing the profile. He desired to draw attention to high earthen dams that had recently been finished, or were still in process of construction, to form storage reservoirs for the city of New York. These dams had generally been built on both sides of central masonry dams or overflow-weirs. As they had been successfully constructed to heights of over 100 feet above the surface (an earthen bank 120 feet high, *Fig. 37*, being now formed as part of the New Croton Dam), it would seem that the French limit of 60 feet for earthen dams might be considerably raised. One of the features of the dams alluded to was that they all contained central core-walls of rubble masonry. This style of construction was adopted owing to the difficulty of finding material suitable for puddle and to the advantages masonry core-walls were thought to possess. Of course, there were many localities where the cost of masonry would preclude its use in earthen dams; but, in comparing the expense of a masonry core-wall with that of an Mr. Wegmann.

Fig. 37.



ordinary puddle core, it must be borne in mind that the former was given a much lighter section that the latter. Core-walls of masonry had the following advantages: (1) If founded on an unyielding, impervious stratum of rock, hard pan, &c., such a wall formed a perfect cut-off in the centre of the dam, preventing water that percolated into the inner slope from reaching the outer one. While a good puddle core might answer the same purpose, it was liable to be washed out in case the water found a channel of leakage along the outlet culvert, &c. (2) The core-wall separated a dam into two distinct portions—an up-stream half that should be made as watertight as possible, and a down-stream half that should be formed of porous material. If these different kinds of earth joined each other, cracks might occur in the centre of the dam on account of differences in settling. (3) The outlet

Mr. Wegmann. culvert was usually carried through the dam, as a lateral tunnel for this purpose was generally too expensive. The greatest danger of rupture of an ordinary earthen dam having a puddle core was generally along this culvert. If it was cracked by the settling of the dam, or the puddle was fissured near the culvert on account of differences in settling, water would find its way into the centre of the bank, and would eventually cause its failure unless the damage were discovered in time. With a masonry core-wall there was no difficulty or danger in constructing the outlet culvert through the dam. The reducers of the outlet-pipes were embedded in the masonry wall. The water from the outlet-tower was conveyed to the reducers in a culvert through the inner slope, the outlet-pipes being laid in a similar culvert in the outer slope. A damage to the inner culvert would not jeopardize the safety of the dam. Any leakage that might occur around the reducers owing to careless work, &c., would be carried off by the outer culvert. (4) With a masonry core-wall, an outlet gate-house could be built in the centre of the dam on the up-stream side of the core-wall, to which it was connected. The water was conveyed to this gate-house either in pipes or culverts placed in the inner slope. If the dam was not high, the inner slope might be omitted at the gate-house, the bank on both sides being retained by wing-walls. A gate-house in the centre of a dam had advantages over a water-tower placed in the reservoir, and insured a tight connection for the outlet pipes. (5) A core-wall gave an earthen dam greater strength to resist the erosive action of water passing over its top. Theoretically, such a case should never occur, as every dam was supposed to have a waste-weir sufficient to discharge the greatest floods that might reach the reservoir; but unprecedented rainfalls led occasionally to the failure of dams on account of water flowing over their crests. The greatest disaster of this kind had occurred on the 31st May, 1889, when the dam across the south branch of the Little Conemaugh River in the State of Pennsylvania was ruptured, causing the loss of more than two thousand lives and of millions of dollars' worth of property.[1] The dam in question was about 70 feet high; its top was originally 10 feet wide and 10 feet above the ordinary water-level. The inner and outer slopes were respectively 2 : 1 and $1\frac{1}{2} : 1$. Watertight earth was used in forming the inner slope and the centre of the dam, but stone was placed in the outer

[1] Report of the Committee appointed by the American Society of Civil Engineers to investigate the cause of the failure. Transactions, June, 1891.

slope. The failure was due to the inability of the waste-weir to pass the water coming from an unprecedented rainstorm. According to competent eye-witnesses, the water commenced to flow over the dam at 11.30 A.M., rising 20 inches over the top. Gradually the water washed a channel at one point through the dam, and rapidly enlarged it until at last at 3 P.M. the dam was ruptured. Considering the fact that the dam withstood the erosive action of the water for $3\frac{1}{2}$ hours, and did not fail until a deep channel was washed through it, it was highly probable that the disaster might not have occurred if the dam had had a masonry core-wall, especially as in this case the outer slope was formed of stone. At all events, it could not be doubted that such a core-wall would give a dam additional strength to resist the erosive action of water flowing over its top. The earth above the core-wall would soon be washed away, but the wall itself would form a long weir which would not fail until the outer slope had been scoured away, and even then the breach made might be comparatively narrow. In designing masonry core-walls, engineers must be guided solely by what experience has shown to be sufficient. It was impossible to calculate the pressures to which these walls were subjected. For high dams, the core-walls were given a stronger section than for comparatively low ones. In the dams built recently in the Croton water-shed, the core-walls had top widths of $2\frac{1}{2}$ feet to 6 feet. Both faces were battered about $\frac{3}{4}$ inch per foot. The thickness of the wall at the natural surface is made about one-sixth to one-seventh of the depth of the water in the reservoir. From the surface to the bottom of the foundation trenches the walls were vertical. These sections might appear too slight, but they had been found sufficient, even when water percolated to their up-stream faces. In two cases leakage had occurred, not through the walls, but through fissures below the foundations. This leakage had been met by suitable drains, and caused no damage. It would be noticed from *Fig. 37* that the slopes were steeper than those usually adopted in England and India; but the sandy character of the earth, of which the dam was to be composed, permitted such slopes. On some other dams recently built in the Croton watershed the inner slope had been made $2\frac{1}{2}:1$. Such a slope was adopted for the earthen part of the Titicus dam, completed about three years ago. Careful observations had shown that this slope had not slid out, the toe remaining in its original position. There had been, however, a gradual settling of the slope proportionate to its height; the maximum being about 2 feet for a height of 102 feet. With argillaceous

Mr. Wegmann.

Mr. Wegmann. earth, the slopes mentioned ($2:1$ to $2\frac{1}{2}:1$) would be too steep. He considered core-walls of masonry had advantages which would warrant their use, even at a considerable increase in cost of construction, whenever the available financial means were not too limited. He knew no case of failure of an earthen dam having a masonry core-wall properly built and founded on an impervious stratum. Two dams with core-walls had failed in the United States during the past twenty years; but in one case the wall had not been founded on an impervious stratum, and in the other the wall was exceedingly light and badly built.

Mr. Strange. Mr. W. L. STRANGE, in reply to the Correspondence, was gratified that Mr. J. R. Bell had brought to notice the distinguished service in the late famine of Mr. R. B. Joyner, C.I.E., under whom he had worked, and who agreed generally with his proposals. Bombay was unfortunately situated, in comparison with most other provinces, as being close to the main watershed; even its largest rivers had not a perennial flow of any extent, and storage reservoirs, although expensive, were there a necessity. As regards the "stepped waste-weir," he thought that, on all works of the magnitude of those under consideration, skilled supervision was as great a necessity as it was on railways. His design reduced to a minimum the time during which careful watch had to be kept. He would point out that the system of dry-stone pitching commended by Mr. Bell was due, not to himself, but to Mr. Whiting. The reasons for his own modification of it were given on p. 150. His drains were placed downstream of the centre-line of the dam, that was, far away from the reservoir, to prevent any flow of water being induced by their presence. This distance would effectually prevent the formation of any current sufficient to move particles of the subsoil. Percolation chiefly showed itself at the junction of the dam with the natural surface; it was of very rare occurrence that even dampness was observed on the slope of a well-made dam. Drains constructed as he had specified should not clog. For the reasons given on p. 164, he thought the compound dam more advantageous for deep rocky gorges, except where the gorge was extremely steep. As regards the most suitable works for famine-relief purposes, the objections, noted by Mr. Dunn, were held by many authorities at the end of 1896; but, by the close of the distress, the almost universal opinion in Bombay was in favour of large irrigation works for the employment of the destitute. These were more easily supervised during construction by the small staff available; in normal years they added some wealth to the country, while in abnormal years they might easily produce crops equal to half or to the whole of their capital cost. If an irrigation work paid its working expenses in normal periods, it might be accepted as a scheme financially sound as regards the country as a whole, although far from being in itself a remunerative one. Each successive famine would thus permanently enrich the country at the expense incurred during and immediately subsequent to its prevalence. During this latter time further assistance to the distressed part of the population would probably be necessary. It must also be remembered that the capital cost of irrigation schemes was very largely increased by the Government system of "indirect charges" debited to them, and this had hitherto greatly minimized the rate of their actual profit-earning capacity. It was pointed out by Mr. Clemens Herschel that ground rollers were employed in America to concentrate the pressure on half their width rather than to assist in kneading and mixing the constituents of the embankment, as he imagined was the object sought by their use. He would prefer increasing the weight of the whole roller, as by a steam roller, so as to secure uniformity of consolidation. A concrete core-wall had once been proposed for the Taílá reservoir, but the proposal was abandoned. So thin a wall might easily be fractured by any unequal settlement of the dam earthwork, and its steep batters would certainly produce a tendency to slipping in the abutting masses of earth which had no bond with it. On the other hand, it might be noted all the American engineers who had dealt with this in the Correspondence were greatly in favour of the system after practical experience of it. The construction of American dams differed much from that of Indian dams, the latter having the advantage of cheap and abundant labour. Mr. John Hopkinson's remarks applied to the total rainfall; but Mr. Strange had in view (p. 130) the individual falls of greatest intensity, which were of more interest from the point of view of the construction of reservoirs. The object of not continuing the drainage of the dam further upstream than the centre line was to interpose a large watertight mass between the drains and the reservoir so as to avoid inducing leakage. The Author was glad to learn that pitching was frequently set in cement in America. If the construction of dams in vertically independent sections, which could each settle without injuring the others, could be attained in practice, the system would have something in its favour, but the great desideratum in all large structures was to have homogeneity and thorough bond. The failure or slipping of one independent part must entail that of the rest. Failures of dams were by no means limited to India, and those which had occurred there were Mr. Strange.

Mr. Strange. probably due to the very large scale of the works. The actual method of construction adopted was excellent; the chief mistakes that had been made were the use of pure black cotton soil, the system of closure and the small attention paid to drainage. The large discharges to be expected from Indian catchments were due to the intensity of the rainfall, the steep slopes of the country and to the general impermeability of the surface. It was rightly pointed out by Mr. L. F. Vernon-Harcourt that the lowest sluices of the stepped waste-weir, being at a high level, would not act as a perfect means of reducing silting. Owing, however, to the greatly increased size of the upper as compared with the lower contours of the reservoirs, only some 40 per cent. of the capacity of Maladevi reservoir was below the weir under the sluices. In the design he had recently submitted, he had gone further in this direction by providing large under-sluices in the outlet head-wall, below which there was no "available capacity" of the reservoir.