Discussion.

Sir John Wolfe Barry.

Sir JOHN WOLFE BARRY, K.C.B., President, thought the Paper most instructive, and well worthy to find a place among the Proceedings of the Institution. The problems connected with Indian rivers, and the great forces of Nature which were brought into operation by the extraordinary rainfalls of that country, were subjects of high interest to all engineers, and enabled them to realize some of the problems with which their Indian brethren had to deal in the construction of the many important works which were now overspreading that great country. In another respect a Paper of that description was still more instructive, because nothing taught engineers so much as hearing the history of failures. It was a peculiar circumstance of their profession that engineers were not afraid of telling their brethren the difficulties they had experienced, and the failures which overtook them from time to time. He was sure that the members would accord a very hearty vote of thanks to the Author for his valuable contribution to the Proceedings, and also for the clear manner in which he had brought forward the various matters to which he wished to direct attention.

Mr. Stoney.

Mr. E. W. STONEY exhibited upon the screen a series of photographs, taken during and after the floods described, showing the damage to the bridges and the methods adopted in their repair.

Sir Douglas Fox.

Sir DOUGLAS FOX, Vice-President, in the absence of Sir George Bruce, wished to say a few words upon the subject, which had been much in their minds for some years in connection with the South Indian Railway. Sir George Bruce had had experience upon the Madras Railway years before, and therefore the South Indian works were carried out with a considerable increase of knowledge in regard to the floods, compared with the earlier days of the Madras Railway. On the South Indian Railway also, although the works were about 25 years old, the engineers had had the advantage of advances in the sinking of deep foundations as compared with work on the earlier bridges on the Madras Railway. The consequence was that the piers on the larger bridges on the South Indian Railway were sunk to a greater depth than had been mentioned in the Paper. In comparison with the Madras Railway they were no doubt improved in regard to the foundations. The floods which had taken place proved

clearly that, having regard to the character of the rivers, it was almost impossible, at anything like a moderate cost, to ensure continuity of the traffic, when those extraordinary forces of Nature were brought into play. The calamities he referred to were comparatively small compared with those of the Madras Company, but still the engineers felt they were rather hardly treated when, on one occasion, as would be seen from the Paper, over 300 tanks burst at once. Each of those tanks was in fact a reservoir of considerable size. The result had been that the headway of bridges, which had in all cases been calculated to give a clearance of fully 10 feet above the highest flood, proved quite insufficient; the water rose not only to the bridge but in some cases to the top of the girders. The result was, as had been very fairly and properly described by the Author, chiefly damage to the superstructure. Owing to the deeper foundations and to the other arrangements which had been introduced, especially that to which reference had been made and which he fully confirmed, viz., the use of the apron, which was the greatest possible protection against the action of a flood of that kind, the damage to the masonry piers was comparatively very slight. Some of the smaller bridges were injured in that respect. As described in the Paper, one pier of one of the larger bridges overturned, but, on the whole, the masonry escaped to a wonderful extent, considering the force of the floods to which it was exposed. One of the bridges had suffered severely in the actual removal of the superstructure. He did not know that this Paper was going to be read, or perhaps he would not have said what he had done upon the same subject on a previous occasion; but he was bound to repeat his remarks. He wished to refer to the damage which was done to one of the bridges which ran into the colony of Pondicherry. In that case there were seven spans of 150 feet each, built on masonry piers. The flood rose to the top of the girders, or very nearly so, and, whilst at that height, a forest of trees, which had been growing on one of the banks of the irrigation tanks, came down upon the top of the flood, piled up against the girders, formed a partial dam, and swept six out of the seven spans into the bed of the river. The piers were uninjured except for about 2 feet at the top, where they were somewhat affected by the movement of the girders. The new bridge was rebuilt upon them. That would show the terrific force which was exercised by the floods of that kind. The difficulty which engineers met with in India was twofold. First, they had to ascertain at what height to put a bridge. As far as his experience

Sir Douglas Fox.

Sir Douglas Fox.

went, that was extremely difficult to deal with. Secondly, the river-beds were not very pronounced valleys; they were wide, with little difference of level, and the river had an awkward tendency to change its course from one side of the wide valley to the other; the consequence being that, wherever the bridge was put, the probability was that it was in the wrong place. At any rate, that had been his experience. It would be observed that, in the case of one flood on the South Indian Railway, no less than 18½ miles of the embankment were more or less seriously damaged. That occasioned a disastrous interruption of the traffic, not for a few days or a few weeks, but actually for months, because a damage of that kind could not be repaired except at great cost and with considerable delay. The conclusion was that the better way to deal with a difficulty of that kind was to let Nature work her own will. There had been an endeavour of late to choose those portions of the embankments which were most likely to be breached, and, instead of keeping the railway at the high level, to bring it down just clear of the dry-weather level of the stream, which was a very small stream, and to construct the railway at that low-level, on a stone causeway with stone ballast thoroughly well consolidated, and to allow the flood to go over the top of it. That plan had been carried out to a considerable extent on the South Indian Railway with success. There had been floods since, and the traffic had been interrupted on one occasion for about a week, but that was the worst that had happened. The floods had come down, and finding nothing to obstruct their course, had passed over the railway, and the damage done had been infinitesimal. Had they to begin again, in many districts in South India, they would be able to save the enormous expense of those long bridges and heavy embankments, and yet to produce a railway which was more certain to maintain continuous traffic than that secured by the present grand and colossal works. In connection with the railway which had just been opened to Buluwayo, his colleague, Sir Charles Metcalfe, M. Inst. C.E., had advised a similar course. It was most important to get that railway opened quickly, and it was decided, as a temporary measure, to run down into the deep gullies which occurred, and to cross the low-level of the water by sand-bags placed in the beds of the streams. The result was that the railway was opened last October. It had been breached, as had been expected, or, rather, its lower portion had been flooded, for a few days. There was during that time perhaps a week, or even 10 days, during which trains could not be run,

but the traffic, with that exception, had been run ever since last October, and the permanent bridges which were to cross those streams would not be ready for traffic until some time in May or June next. That was of great importance to the country, and he thought that, not only as a temporary expedient, which it was in that case, but as a permanent expedient in many instances, it was far better, where serious floods recurred, as they did in India, not to attempt to resist them, but to allow Nature to have her way, and to let the water pass over the railway. Sir Douglas Fox.

Sir BRADFORD LESLIE, K.C.I.E., thought the inference drawn by the Madras engineers from the stability of irrigation weirs, namely, that shallow foundations for piers of bridges would be safe, was evidently unsound. It would have been right if a continuous curtain-wall of wells above bridge, with a concrete flooring and an apron of rubble stones below bridge, had been provided. Isolated piers founded on sand at shallow depths, unless liberally protected by rubble stones, when attacked by a strong current, simply dug their own graves and toppled over into them. The absolute stability of a shallow foundation bridge, if protected by flooring and rubble stone to arrest under-scour, had been proved by the flood openings on the Eastern Bengal Railway, which stood the rush of the Ganges spill not for hours only, but sometimes for weeks at a time. The Author's observation, that many of the minor bridges on the South Indian Railway, which were protected by floors and aprons, stood well while discharging for several hours under a head of 8 feet, confirmed that fact. The Kurnowtee bridge on the East Indian Railway had a 20-foot brick arch with an invert in a 30-foot embankment. That bridge had frequently been entirely submerged, with the flood-water squirting through it, under a head of 8 feet for days together. The force of the water had scooped out a deep pond 20 feet deep on both sides of the embankment, but otherwise the bridge stood uninjured and had carried the traffic of the East Indian Railway for years to the present day. That showed the great stability of a properly floored bridge protected with aprons and with an invert. In deep perennial rivers, or when the cost of curtain-walls and rubble-stone and continuous flooring became too great, it was necessary to have recourse to cylinder piers. It was remarkable that the late Mr. Brunel recognised from the first the necessity for deep foundations for piers of bridges over the sandy beds of Indian rivers. For the Echumuttee and Koomar river bridges in 1859, Mr. Brunel had sent out cast-iron cylinders 8 feet in diameter, sunk into the river-bed by the pneumatic process. The actual depth to which Sir Bradford Leslie.

Sir Bradford Leslie.

they were sunk and which had happily proved sufficient, was 40 feet below the river-bed. But Mr. Brunel intended them to be sunk deeper. He well remembered, after the work was finished, a considerable quantity of surplus cylinders remained. Those bridges for the last thirty-seven years had been subjected to very heavy floods, but beyond requiring a little rubble stone to limit the scour, they had never given any trouble. In lower Bengal, unlike the inclination of the Madras river-beds which was something like 10 feet or 12 feet per mile, the tilt of the delta was only 6 inches in a mile, and the inclination of the river-beds, owing to the winding course of the river, was perhaps only 3 inches or 4 inches per mile. The flood velocity of the Ganges was not less than 7 feet or 8 feet per second. That high velocity with such a low fall was accounted for by the great scour which took place at the same time as the flood rose, so that when the flood rose 20 feet or 30 feet, there was a corresponding scour; and with a flood rise of 20 feet, there was an increase of something like 40 feet in the total depth, owing to the scour. The belief expressed by the Author, that during high floods the sand was in motion to considerable depths, might be correct in the case of the Madras rivers with a fall approximating to 12 feet per mile, and was confirmed by the fact that many of the piers that failed canted down-stream, or were found to be leaning considerably down-stream. He did not, however, think that in the Punjab rivers the sand was in motion to any appreciable depth during high floods, though the whole surface of the river-bed was rolling down-stream and was constantly being replaced by alluvium from above. When the piers of the Sutlej and Beas bridges failed in 1871, they gradually tilted and finally fell over up-stream, showing that they were fairly under-scoured and were not forced over by the pressure of the current and moving sand. The points brought out by the Paper, and which seemed to him worthy of the attention of Indian engineers, appeared to be, first, the great value of large rubble stone, or rip-rap, for arresting scour. The Author wisely invited attention to the efficiency of such rough stone protection against scour. The fact that the sleeper-stack pier, built on the surface of the river sand, withstood the flood owing to the protection of boulders placed round it, was remarkable when so many massive stone piers were overthrown. That confirmed the value of the rubble protection. The second point was the great danger of the lateral flow of flood-water along the line of embankment. Such a current swinging round when it arrived at the bridge opening took the piers in flank, causing

violent eddies, which bored out the river-bed to unknown depths. Damage of that nature had been referred to by the Author at the old Cheyair bridge, where the flood-waters ran along the railway embankment, causing a current to flow across the river, which attacked the piers in flank, scouring out the sand-bed of each pier in turn. Again, at the Chittravati bridge, it was stated that the destruction of the masonry piers on the left side was partly due to their being attacked in flank by a cross-stream current; also, when the Author was constructing the new Chittravati bridge, there was a strong diagonal current across the river, so much so that the water on one side was 1·56 foot higher than on the other side. The most recent practice at the Sher-Shah bridge on the Chenab in the Punjab and the Krishna bridge on the East Coast Railway, was not to allow the river to straggle about over a wide valley or shallow depression. There was no object in bridging the entire breadth of the flood-channel, thereby exposing a long length of bridge to the attack of the floods. At the bridges referred to, the Sher-Shah and the Krishna bridges, a bottle-neck had been formed by training embankments, protected by rubble stone, thereby restricting the width of the bridge to that necessary to discharge the maximum flood after allowing for a limited amount of scour to adjust the sectional area to such discharge. It was dangerous to venture an opinion without being in full possession of the facts and data, but judging from the elevations only of the Madras bridges, it seemed probable that the new Cheyair, the Papaghni and the Penner bridges might have been considerably reduced in length, thereby effecting a great saving of cost. He was confident there were still many other bridges in Upper India which might with advantage be curtailed in length by contracting the width of the river by training embankments, thus guiding the flow of the flood-water in a direction normal to the bridge, and preventing the lateral scour which had been so destructive to many piers. Another point referred to in the Paper was the use of continuous girders, which effected a great saving of weight. He thought it was to be regretted that the use of those girders had gone out of fashion. The idea was that the slightest settlement of one pier would strain the girders, and that therefore it was not safe to use them; but although he had known of many piers being capsized by underscouring, he had never known of an instance of a pier after it had been sunk and filled with concrete, settling vertically; therefore he did not think there was anything in that objection. He thought that the superstructure of the old continuous girder bridges was

Sir Bradford Leslie.

Sir Bradford Leslie.

more economical and really better than that of the new heavy bridges, with the train passing between the girders which had been substituted for them. The use of continuous girders with the rails running over the top also permitted the use of single-well piers, by which great economy was effected. Single-well piers, sunk to a sufficient depth and protected by rubble stone, were absolutely secure. He did not think that for a single line of railway there was any necessity to use double-well piers. If those points were attended to more, he thought it would result in great economy in bridge construction in India, combined with absolute stability, and would enable engineers to do more with a given amount of capital.

Mr. Symons.

Mr. G. J. SYMONS thought the members could not have seen the photographs exhibited without feeling how responsible and serious an undertaking it was to build bridges which had to resist such floods as those described. He was afraid they looked sometimes a little too much at the engineering features, and too little at the physical geography, which caused all the trouble. The essential feature in the Paper was the discharge of an enormous amount of rainfall across the line of railway. One of the photographs showed the watershed area, and one of the watersheds was shown in Fig. 1, Plate 2, but he could not help thinking that something a little better and more important might and could be given with advantage. For instance, in relation to the rainfall results he thought the positions of the gauges ought to be marked on the map. With regard to the second portion of the Paper, there was no watershed map to indicate the sites of the returns given by the Author, and there were no latitudes and no longitudes; and there was also no reference to the rainfalls of previous years. The rainfall of India had been taken at certain stations before and through the mutiny, and from about 1862 onwards there had been a thoroughly good organization in India for recording rainfall. The first Table gave returns at about five or six stations in 1874, and he had tried to find whether there was anything exceptional in those rainfalls. At Madanapalli in 1874 the rainfall during the 6 days was 9·8 inches—just about 10 inches. On turning to the Madanapalli records he found that the fall in a single month had exceeded 10 inches six times since 1873, the first occasion being in October, 1873, when, as compared with 10 inches in 1874, there were 17 inches, or nearly double. He did not find in that Table four other gauges, all of which were on the watershed either of the Cheyair or of the Papaghni—either on the watershed or

close to it, so close as to be thoroughly useful. They showed the same thing; they showed larger falls on previous occasions than those which did the damage in 1874, except with regard to one station, Cuddapah (Lat. 14° 26', Long. 78° 51' E.), (not quoted in the Paper) which in September, 1874, gave 30·55 inches. He would not deny that that would justify any amount of flooding, but he ventured to think that the Author was perfectly right in his remarks—the Author did not say so in so many words—that the mischief was not due to the rainfall, except indirectly, but was really due to the large series of tanks along the rivers, No. 1 going, and then carrying away Nos. 2, 3, 4, 5, 6, and 7, and all the rest. The 1874 rainfall he had already shown to be (with one exception) not unprecedented. With regard to 1884, the figures of which were given in the Appendix, he had compared those with previous records, going back to 1864. Taking, in the first instance, Vellore, which in October, 1884, was 11½ inches, and in December, 14½ inches, he found that only two years before it was in November 23·58 inches, and there was a great number of instances of 10 inches and upwards. At Arcot in October, 1884, the rainfall was 14½ inches, and in December, 15 inches; and about a dozen previous instances were given, the maximum being in 1882, two years earlier, when it was a little over 20 inches. And so on through several of the others; and although he was not going to suggest for a moment that the rainfalls, as shown in the Appendix, were not very remarkable and very difficult facts to have to deal with, still he did not think they could be regarded as at all unprecedented. He ventured to think that it would be a convenience if, in studying such questions, a little more research was made into the past history, and into the information which had been collected throughout the country. Those great rainfalls must be fearful to have to deal with, and he could only congratulate engineers upon being able to combat them at all.

Mr. Symons

Colonel Pennycuick (late R.E.) had listened to the Paper with great interest because he had a vivid recollection of the particular floods to which the Paper alluded. The district of North Arcot, of which he was in charge at the time, was the one that suffered most severely in the whole of the Madras Presidency. He had also a vivid recollection of what the Author's modesty had prevented him from mentioning, namely, the admirable manner in which traffic was re-established by the Author and his colleagues after the very heavy damage to the Madras Railway. He thought the facts brought forward showed that railway engineers in India

Colonel Pennycuick.

Colonel Pennycuick.

would often have saved themselves a great deal of trouble and a great deal of expense if they had made use of the information which they might have obtained from their colleagues in the Public Works Department. Looking at the sections of those particular bridges, especially of the Cheyair and Papaghni bridges, the first thing that struck one was the extraordinary weakness of the foundation; his own feeling was one of astonishment that they had not given way long before. Sir Bradford Leslie had anticipated a good many of his remarks, but he would like to add his own experience in Madras. The Madras system of shallow foundations was perfectly well known and had been practised for centuries, and successfully, not only with weirs where the conditions were different, but in regard to road bridges and anicut sluices which had far heavier trials in the way of velocities than anything referred to in the Paper. In the case of the Cavery and Vennar regulators, the entire flood discharge of a river ten times the size of those mentioned in the Paper had been dealt with. The essence of the system of shallow foundations which had been used so successfully for years, was that the piers should be protected by horizontal protection, aprons being thrown out all round the pier. Most bridges, of course, were of masonry with comparatively small spans, and the flooring was continuous from end to end, a curtain wall either level with the cut-waters of the piers, or, as he himself preferred, rather beyond them, and dry-stone aprons beyond those again. Those had been completely successful, and he might venture to say that an amount of safety was obtained with much less expenditure than could be obtained with the enormously deep piers which were now becoming the fashion, deep cylinders going down in some instances in the north of India between 120 feet and 150 feet. Another point which had been alluded to in the discussion and in the Paper was the breaching of tanks. In future he was happy to say that would not take place to the extent it had done in former years. During the last 14 or 15 years in Madras more systematic attention had been given to bringing the tanks into order, and to providing them with proper escape weirs and to keeping the embankments in order. It was too much to expect that freedom from the breaching of tanks would ever be attained. A considerable number of tanks, not any of the largest, but some of the moderate-sized class, were not the property of the Government; the Government had no control whatever over them. He had not the slightest doubt that the Author would recollect the Carvetnagar case very well indeed, in which the House of Lords practically decided that there was no remedy against the landowner who

allowed his tanks to go to pieces, and thereby destroyed a railway. It was impossible to exaggerate the damage done to embankments and to minor bridges by the bursting of tanks, but very easy to exaggerate the effect on large rivers, and he thought that the Author, and still more Mr. Symons, had done so. The great damage done by the bursting of tanks was on the way to the rivers which formed the great drainage channels of the country. When once the contents of the tanks got into the rivers they were lost in the general rainfall of the country. Looking at the figures given in the Paper, he found that the valleys in which the greater number of tanks burst, in which the addition to the floods from the bursting of tanks was the greater, were those of the Cheyair and Penner. Those were the two which, compared with drainage areas, gave the smallest coefficient of discharge in the four rivers dealt with. In the Chittravati basin comparatively few tanks burst, and those not of great importance; and in that of the Papaghni there were very few more. Yet those two rivers gave a discharge far greater in relation to their area than Cheyair and Penner. He had no doubt the Author could give figures which would correct him, but he believed he was right in saying that in neither the Chittravati nor the Papaghni basin did the aggregate contents of tanks, which breached during the six days preceding those floods, exceed 500,000,000 cubic feet, which was $\frac{1}{10}$ inch on the drainage basin of either of those rivers, and that was nothing compared with the actual rainfall of 12 inches or 14 inches which fell previously. He wished to appeal to the Author for information on one point. One of the greatest difficulties to be dealt with in India was the want of knowledge as to what to expect in the way of floods. Every piece of information which tended to remove that ignorance was of value. The Author was so well known and so respected in Madras that he felt some diffidence in criticising any of the figures which were put forward by him, but he could not help being a little sceptical about the discharge of the Papaghni as compared with the two basins on either side of it, the Cheyair and the Chittravati. There did not seem to be anything in the records of rainfall, or in the sections given in the river, to account for the enormous difference between those discharges in basins of very similar character. To estimate the discharge of a river of that sort in high flood when there was a very ill-defined river-bed, still more when there was an ill-defined section, and when the exact depth at which the sand was moving was not known, was exceedingly difficult. He thought it would be of great value to everyone interested in hydraulic work in

Colonel Pennycuick.

Colonel Pennycuick. India, especially in the south, if the Author would give in detail the data, which no doubt he would be able to do, on which he had obtained the velocities and discharges.

Mr. Mansergh. Mr. JAMES MANSERGH, Vice-President, asked the Author if he knew the aggregate contents of those 330 tanks which had burst in one of the valleys. The destruction of 330 tanks sounded a very serious matter indeed; but one would be able to appreciate more clearly what it really meant if it were known more or less what their capacity was. Colonel Pennycuick had said something about 500 million cubic feet, but he had not clearly followed what was referred to.

Colonel Pennycuick. Colonel PENNYCUICK said that the 330 tanks burst during the later flood on the South Indian Railway; he was speaking of the Chittravati and Papaghni valleys in 1874.

Mr. Stoney. Mr. E. W. STONEY had taken the information as to the South Indian floods from a Government Report, in which the figures were given, but nothing was said as to the contents of the tanks. The tanks varied so widely in size that it would be very difficult to state the aggregate contents.

Colonel Pennycuick. Colonel PENNYCUICK continued, with regard to the bursting of tanks, his own experience was that, as a general rule, it was the smaller tanks that breached. It was very rarely that the large tanks breached, because they were generally better provided with waste-weirs, and possessed a larger margin between the top of the bank and the waste-weir. The tanks which burst were almost always the small ones, and some of them were insignificant. As an instance of what he had stated as to how little the breaching of the tanks affected the discharge of rivers, he would mention the Palar in North Arcot. That river was in very heavy flood on the same day as the Cheyair and Papaghni bridges were destroyed. The Palar bridge at Vellore was damaged and the anicut at Arcot was carried away, and the coefficient of discharge of that river was considerably higher than either of the four rivers mentioned in the Paper except the Papaghni; and in that valley, to the best of his belief, not a single tank breached, for the very sufficient reason that every tank in the valley had breached in August. The greater number of the tanks in the Upper Palar were situated in Mysore, and all through July and August he received telegrams from Sir Richard Sankey, the Chief Engineer at Mysore, warning him of the floods in the valley and the possible breaching of tanks. About the middle of August he received a telegram to say that the last tank in the Palar valley had breached, and, in spite of that, the flood in October, 1874, was heavier than

any known in the district before. He believed that the Palar had actually a higher coefficient of discharge than any other river in the South of India. Colonel Pennycuick.

Mr. JAMES MANSERGH asked what would be the capacity of a small tank—160 million cubic feet or 16 million cubic feet. Mr. Mansergh.

COLONEL PENNYCUICK had endeavoured to obtain from the Administration Report of the Madras Irrigation Department results which would enable him to estimate the contents of the tanks referred to in the last portion of the Paper, and he thought that one very fair estimate might be obtained from the statements of revenue lost through the breaching of the tanks. A study of the figures had satisfied him that the whole area irrigated by the tanks which breached in November and December, 1884, in those districts affecting the South Indian Railway between Madras and Porto Novo (that is, in the districts of North Arcot, South Arcot, Salem, and the southern point of Chingleput) did not exceed 30,000 acres, and these breaches were divided between two floods, separated by an interval of 6 weeks, so that the area under tanks breached in either of these floods could not possibly have exceeded 20,000 acres: 150,000 cubic feet per acre was a fair average for the contents of a tank, so that the total amount let loose in either flood could not have exceeded 3,000 millions of cubic feet. This amount of water had to cross the South Indian Railway by five rivers, the Palar, the Gingi, the Pooniar, the Gudilum and the Vellore; the aggregate drainage areas of which amounted to over 18,000 square miles, on which area 3,000 millions of cubic feet represented a depth of just $\frac{1}{1\frac{1}{4}}$ inch. The Author mentioned the Kurunguli bridge as one of those injured by the flood of December, 1884. The Kurunguli bridge carried the South Indian Railway across the surplus of the great Kurunguli tank, which was one of the largest and most remarkable in the Madras Presidency. It closed the valley of the Oleear, a tributary of the Palar, which was joined a little below the crossing of the South Indian Railway. The Oleear valley contained a large number of tanks (he believed about seventy), the surplus of the whole of which ran into the Kurunguli tank. In October, 1874, every tank in this valley, with the exception of the Kurunguli tank itself, breached, and, as the latter was quite full at the time, the flood began. The whole of their contents must have been received by the latter, and passed out by its surplus works into the Oleear. Yet the flood in this river was less severe than in 1884, when comparatively few of this particular series of tanks were breached. He thought that these facts bore out his conclusion that the Colonel Pennycuick.

Colonel Pennycuick.

breaching of tanks had only an insignificant effect upon the floods of large rivers. He wished to be allowed to add a few words on a very interesting point alluded to by Sir Bradford Leslie, who stated that in his experience in Northern India he had found that when a bridge-pier yielded to scour it usually fell up-stream. He could give from his own experience two rather remarkable instances bearing on this point. In 1872 he was appointed a member of a committee to inquire into the cause of the destruction of a large bridge over the Vellore river, near Porto Novo, the other members being two gentlemen well known to many of those present, namely, Mr. Robinson, then Deputy Chief Engineer, and afterwards Chief Engineer, of the Madras Railway, and Mr. Logan, Chief Engineer of the South Indian Railway. Their examination showed clearly that only one pier had been really injured by the flood, the others having been overthrown by the thrust of the arches when this one gave way, and this pier had sunk between 2 feet and 3 feet on the up-stream side. In October, 1874 (during the floods described in the Paper), the bridge on the Palar near Vellore was partially destroyed, and an examination of the site showed that exactly the same thing had happened, except that two piers situated some distance apart had given way simultaneously, or nearly so. Each of these had sunk considerably on the up-stream side. Remembering what he had observed in the case of the Vellore bridge, he came to the conclusion that the principal danger from scour was at the up-stream end of the piers; and, in re-building the bridge, he determined, contrary to what was then the usual practice, to place the principal protection on the up-stream side, making the apron considerably wider on that side than on the other. His action was much criticized at the time, but he had never seen cause to change the opinion which he then formed and which he was glad to find was confirmed by Sir Bradford Leslie's experience.

Mr. Horace Bell.

Mr. HORACE BELL thought the most peculiar and perhaps the most interesting feature of the Paper was the fact that both the railways referred to by the Author were subject to damage by floods from the irrigation reservoirs in the vicinity of both lines. Insufficient stress was laid upon the fact that the principal damage resulted not so much from the increase to the flood-level or the flood discharge of the rivers with which he had dealt, as from the fact that the tanks, in breaking away into the residuary catchments, ran along and injured the embankments and carried away or damaged the smaller bridges. He agreed with Colonel

Mr. Horace Bell.

Pennycuick that the breaching of the dams of the reservoirs did not so materially affect the flood discharge of the rivers as to make it a serious consideration in dealing with their waterway or foundations. He had visited both the lines in 1893, and at that time the South Indian Railway had been more or less damaged in a similar way to that which the Author had alluded to. It was evident that the escape channels were not properly controlled, because in one case where the South Indian Railway ran through a very large tank, he noticed that the flood-level was lapping the top ballast, and a little more would have practically destroyed the road and rendered it impassable. On returning to Simla, after visiting those lines, he made it his duty to see what attitude the Government had taken towards preserving the lines from such floods, but his impression was that the Government of India were not disposed to take any other view than that the tanks were there before the railway, and that the railway must take care of itself. Both of the lines were not merely of local importance; they were arterial routes carrying a very large traffic, and moreover, lines in which the Government of India, as the co-sharer with the railway companies, was much interested. Although the breakage of tank-dams did not seriously imperil the large bridges, he thought it possible that in the case of the breakage of a chain of tanks, there might be what he would call localization of high-flood level in a part of the flooded area, so much so as to damage perhaps one or two or more of the piers of a large bridge; but he did not think that even the breakage of a chain of tanks in one small subsidiary catchment-area would materially affect the level of such comparatively large rivers as those referred to in the Paper. He thought Mr. Symons was rather unkind to the Anglo-Indian engineer regarding his ignorance of the rainfall in the catchment-areas with which he had to deal. In the first place, in the tropics, or in sub-tropical regions, heavy rainfalls were essentially local, and no satisfactory data could be obtained for such large catchment-areas as were involved in the rivers to which the Author had referred without a number of stations that would be impossible in India. In many cases rivers had to be bridged before any stations had been established; so he thought they must claim to be exempted from any blame on the score of ignorance of the rainfall in many cases. It had been mentioned by Sir Douglas Fox that cases of severe floods might be dealt with by using what were irreverently called at one time Irish bridges, or causeways, instead of trying to bridge the whole of the flood section. Under certain conditions, that might be feasible; but he did not think Sir Douglas Fox intended that Irish bridges

Mr. Horace Bell.

or causeways would be suitable for lines of communication which had to carry a large traffic. The causeway was not new in India; it was used to his own knowledge on minor lines of railway, and largely on roads, and was very useful, because it mattered little—as Sir Douglas Fox had pointed out—if a small line of communication, whether road or railway, on which the traffic was small, were blocked for 24 hours or more. It would perhaps be also noted that the bridges to which the Author referred were possibly too long, and allowed the discharge to take a diagonal course, this being probably a contributing cause to their having been so frequently damaged. Perhaps the Author might be able to say why, in the new bridges, he had adopted through spans instead of deck spans in the new bridges. He thought it might be established that there would be considerable saving by using deck spans and raising the rail-level.

Mr. Vernon-Harcourt.

Mr. L. F. VERNON-HARCOURT said that in the case of Indian rivers a large quantity of sand was brought down from above. One had only to observe the Sone, near its confluence with the Ganges, in dry weather, to see a vast expanse of sand; and with regard to the Hooghly, which he had to investigate, most of the shoals of that river, though not quite all, were pure sand. He need hardly say that the Hooghly was a very turbid river in appearance; but the difficulties encountered in navigation were chiefly due to the sand that was brought down from above, principally, he imagined, by the tributaries of the Bhargirathi, and also to some extent by the inlets from the Ganges. In other parts of India, clearly the same abundance of sand was brought down, because looking at the eastern coast of India along by the Bay of Bengal and the Indian Ocean, the river outlets were in most cases deltaic, in spite of the rise of tide that took place, amounting to something like 12 feet or 13 feet at spring tides in the Bay of Bengal and diminishing to about 6 feet at Madras. The Ganges, the Mahanuddy, the Godavery, the Kistna, and Cauvery were instances of deltaic rivers, which showed that there were large quantities of sand brought down from above, and carried eventually to the mouths of these rivers, causing their deltas. What doubtless helped in bringing down these large volumes of sand and other detritus, was the exceptionally heavy rainfall that took place in a very short period, causing a rapid flow, and therefore readily bringing down vast quantities of material. Referring to what had been said as to the dearth of meteorological records of rainfall, as far as he was concerned, having had to look at those which had to do with a small tract of country in

Mr. Vernon-Harcourt.

Bengal, he thought the records kept in the meteorological office at Calcutta were remarkably well compiled and fairly numerous. One could not expect to have the same proximity of rainfall stations in a large country like India, as was practicable in a thickly populated country like England, where people took much more interest in meteorological studies than the natives in general of India. He hardly agreed with Mr. Horace Bell in calling those catchment basins shown on Fig. 1, Plate 2, large basins, because, after all, in comparison with several Indian rivers, they were certainly small river-basins, being mostly tributaries of the Penner. He noticed that even the Penner, above where the bridge was made across it, had a catchment-area of only 4,062 square miles—less than the basin of the Thames, which, compared with continental rivers, would be a very small river if it were not for the tide. With regard to the question of floods, he thought the Author was quite right in supposing that the sand was in movement for some distance below the surface. In studying the Hooghly, the only way that he could account for the changes that took place, and nevertheless for the kind of stability that there was in the general channels of the river and in the depth, was that when a flood commenced it not only brought down a large quantity of material, but it also carried along a good deal of the material that was deposited at the end of the previous flood. It therefore carried along both the old and the new materials during the height of the flood, and, towards the end of the flood when the current slackened and the discharge decreased, it dropped them in the ordinary course of things. It was very curious that a river like the Hooghly, which brought down large quantities of material in the flood season, should have such a remarkable permanence of depth in its channels. Pure sand was readily scoured; and the charts of the Hooghly showed that where scour occurred owing to an eddy produced by the configuration of the banks, a very deep hollow might be maintained, in spite of the quantity of alluvium brought down. At some places there might be as much as 10 fathoms in depth at the lowest low water, whereas not very far off, and in the main navigable channel, there might only be between 2 fathoms and 3 fathoms. He came to the conclusion, in studying the Hooghly, that it would be very undesirable to put any detached work on the bed of that river, because the scour that would take place on both sides in that case upon the sandy bed would be sure, sooner or later, to undermine such a structure; and it could only have been a question of time when the old bridges shown in

Mr. Vernon-Harcourt. the Paper would be undermined. If it was considered that the rivers referred to in the Paper were not only flowing with water, but also that the sand was in movement, as had been noticed before now in the Mississippi, where sand-waves travelled down the river—and the larger the flood the deeper was the movement —it was evident that eventually there must be scour leading to the undermining of some of the piers which were founded at a comparatively small depth in the sand. With regard to the statement that was put forward by Mr. Stoney, no doubt in excuse for the old engineers who built their piers upon sand, that they had formerly built stable weirs across rivers in India on sandy beds with wells, the difference was considerable. In that case he believed the wells were put down as sheet piling would be driven under the sills of a dock, or even of a weir, in order to prevent any undermining by a flow of water underneath. In those instances the flood waters passed over the weir, and there was no movement of sand along the river under the weir, which, no doubt, took place generally in the beds of those rivers. It was probably true in most cases that Indian rivers did change their beds. He had an opportunity of observing that also in inspecting the inlets from the Ganges into the Bhargirathi, where it was possible to walk across one of the old silted-up beds of the inlets. Nevertheless, with regard to the Hooghly, its bed was remarkably stable, and had been so for a great length of time. The fact of there being pure sand in those rivers gave an opportunity for training, which otherwise, if there were a large admixture of silt, would not be the case. The Author mentioned the cross-current which took place during floods, which he noticed even across the larger openings of the new Chittravati bridge. It certainly would seem objectionable that there should be that cross-current. For one thing, a cross-current like that would tend to silt up the bed of the river below the bridge; and it would seem desirable, now that the foundations had been carried to a sufficiently deep level, to bank out the flood from the low level to the south and to make the river scour its own bed in the proper course; which would be an advantage in diminishing floods when they occurred by providing a straighter, larger and deeper channel, because now there was no fear of the deep piers that had been put up for the new Chittravati and other bridges being undermined. Such embankments for guiding the rivers would be of advantage both to the rivers themselves and also to the lands along their banks.

Mr. J. R. Bell. Mr. J. R. BELL remarked that, in the time of his predecessor, Mr. Horace Bell, the railway systems of India had already covered,

he might safely say, 2 hours of longitude—one-twelfth of the whole earth's periphery; and most varied conditions were necessarily met with under those circumstances. He thought it should have been mentioned in the Paper that the areas under contemplation, both that occupied by the Great Southern of India Railway, mentioned by Sir Douglas Fox, and by the Madras Railway, to which the Paper more immediately referred, were included in the most peculiarly and distinctly cyclonic zone known on the face of the earth. When in charge of the East Coast Railway, a little further north he had observed and gauged a rainfall of no less than 21 inches in two showers, which occurred within 24 consecutive hours. The morning of the first day, up to 10 o'clock, was very fine and hot, and the afternoon was again dry; then there came a second shower in the early morning that completed something over 20 inches of rainfall in his particular compound at Waltair near Vizagapatam. Under those conditions, he agreed with Colonel Pennycuick, that the effect of a chain of minor tanks breaching in sequence was relatively small. He had begun his Anglo-Indian career under the same eminent chiefs as Colonel Pennycuick—Colonel Anderson and other great masters of Indian engineering, whose most famous school was Madras. There he had the duty of surveying several such chains of tanks as those alluded to in the Paper. The tank systems of Madras scarcely trapped at the outside more than 1 foot of rainfall for the catchments that they represented. He did not think that any tanks remained nowadays on what might be called dangerous catchments. On the contrary, they only trapped slight depressions which were scarcely streams at all, and, by a process of natural selection, dangerous village tanks were gradually eliminated. He supposed that tanks had a deleterious effect on the question of railway bridging, mainly because they trapped the greater part of that silty alluvium which formed a concomitant part of what all rivers carried; and it was certainly the fact that alluvial rivers elsewhere built up their banks by continually adding wedges, so to speak, of silt. Every time such a river overflowed its banks by inundation it deposited silt, necessarily in the form of a wedge, with its butt more or less on the bank of the stream and its thin edge tapering out into the plain, so that gradually the rivers built themselves up on a kind of mound, but incidentally embanked themselves within certain limits. These limits were not very narrow; for instance, the Upper Indus, for a great part of its course, from Kalabagh downwards, had a main width of about 9 miles, within which the channels wandered about. In Madras, as far as he had seen, the building-up action

Mr. J. R. Bell.

Mr. J. R. Bell. did not take place. On the contrary, it had been found necessary and even safe, to *levee* the rivers by more or less temporary clay embankments. That, he thought, was the principal way in which tanks affected these rivers. It might be practicable to throttle these rivers, in what Sir Bradford Leslie called a bottle-neck, when the bridges had such large spans as 140 feet, with piers sunk to the rock; but his experience of Madras led him to doubt whether it was advisable to so throttle those rivers as to cause them to scour until they would have what he might call a deep regimen. Every river, as far as he knew, tended alternately to spread itself into fords and then to deepen itself into pools. Hunger*ford* and the *pool* at London bridge were, he supposed, local examples of a case which was universal. He supposed that, after any river had spread itself over a wide area, the water tended again to contract itself into more or less defined channels and to create a certain amount of scour. But, having seen the bridges and rivers mentioned in the Paper, he was convinced that the sand of these rivers, which came from the Nilgiri and Mysore Mountains, was very different from the Himalayan sand dealt with in the Punjab; and that the amount of scour possible in the way of forming deep channels in the lower Madras rivers, was far less than what he and others had been accustomed to in the rivers of Upper India. His conclusion was the same as that of Colonel Pennycuick, viz., that if the Madras Railway engineers had followed the practice of their predecessors in its entirety, and had made a weir of each bridge, protecting its piers all round with stone, while deepening the middle of the spans, he had little doubt that the old 64-foot spans of the Madras Railway would still be standing.

Sir Guilford Molesworth. Sir GUILFORD MOLESWORTH agreed with Mr. J. R. Bell that the rivers of Madras were very different from those of the Punjab, where generally the rivers were on high ground. They fluctuated, and had an enormous flood; their course lay, as it were, in bends, curving in their main channels alternately from one side of the river-bed to the other. One year they might strike one part of the edge of the river-bed, and another time they might strike another part. On railways which followed the general direction of such rivers, the works were sometimes exposed to heavy floods in parts; at other times in heavy floods those parts enjoyed perfect immunity from flood. With regard to Mr. Vernon-Harcourt's remarks, he remembered the engineer-in-chief of one of the railways reporting to the Government of India that floating sandbanks were coming down the River Sutlej, and he proceeded to account for the pheno-

Sir Guilford Molesworth.

mena on the assumption that there were accumulations of bamboos and brushwood which had fallen into the river, and sand had drifted upon them, and that they were floating down the river. The sketch the engineer had sent induced Sir G. Molesworth to think that it was not a floating sandbank, but simply a sandbank on which the water coming down, saturated with silt, eroded the nose of the sandbank, and then it deposited the eroded silt in the dead water in the rear. That sandbank would apparently travel down at the rate of nearly 100 feet in a day. He advised the engineer to put a flag on the sandbank, and to take theodolite sights on it, with the result he expected, that the sandbank did not move; it was simply eroded. With regard to what Mr. Horace Bell had stated as to the size of the bridges, he thought that often a bridge might be a great deal too large for the flood it had to carry. The stream wandered about, and very often, as he thought the Author had stated, ran almost parallel to the bridge across it. It was very difficult sometimes at the outset, however, to reduce the size of those rivers. The Chenab was a river with about 3½ miles width of bed and with back channels. It would have been impossible at the outset to reduce that to reasonable proportions compared with the flood it had to carry, because it would first be necessary to train the river above the bridge-site. The training works had to be commenced 3½ miles above the site of the bridge. The result was that had the bridge been narrowed at the outset, it would have involved great delay in commencing the work. He reduced the bridge, which was more than 1½ mile in length, from time to time, and during the Afghan War he took six spans from it. It was reduced further and further as the training works were advanced, and rendered further contraction admissible. There was no doubt that the more the river could be reduced within reasonable limits the better the flow through it would be concentrated, but he thought that policy might be carried too far, because there was the great danger of damming up the stream so much that being on the higher ground it might break through some miles above and perhaps take another course altogether. He had been responsible for the contraction of the Chenab bridge, and he did not feel at all sure that he had not overdone it, because some of the training works had been breached and part of the river had run through the back channel. Still he thought the principle was right to have the river concentrated as far as was practically safe. The plan he generally adopted in a large river was to have a "pier-abutment," which was like any other pier, only there was a large cone of stone round it. He generally almost floored the

Sir Guilford Molesworth.

first span on either side with loose stone, gradually making the floor lower and lower, so as to draw the stream as far as possible away from the abutment. He advocated the use of loose stone in preference to anything like masonry, because the loose stone adjusted itself to the wear of the river, whereas any masonry that might be undermined was lost. In the Punjab the engineers had well foundations to deal with, and were taught a good object lesson by the Sind, Punjab and Delhi Railway. A lot of piers were sunk 40 feet deep, but without any protection of loose stone. The result was that a large number of them were carried away, although founded 40 feet below the bed of the river. He had even known, in one case, piers carried away when the foundations had been sunk as much as 70 feet below the bed of the river. The instructions which he had given to cut down the wells and to heap stone round them before the rains set in, were unfortunately not carried out by the engineer in charge. No blame attached to the engineer, because he was very busy and the rains came on suddenly, but still three of the piers fell, undermined, even though founded at a depth of 70 feet. The curious part was that the up-stream well fell first. Wells were generally surrounded with loose stone, laid in a flat ring round the pier, and as the stone was undermined it gradually spread itself out, so that the well was supported by a cone coated with loose stone. He generally preferred to put the stone in a larger quantity above the up-stream side than down, so that when the undermining action occurred the loose stone took its proper place. In some cases it was necessary to have a floor of loose stone across the stream, so as to prevent a deep scour, but, as a general rule, he preferred a deep scour in the middle of the stream to keeping a shallow bed all the way across.

Mr. Stoney.

Mr. STONEY, in reply to the Discussion, desired to draw attention to the sections of the beds of the Cheyair, Chittravati, Papaghni, and Penner rivers, Plate 2, which were instructive, as showing the variety of strata which lay between the surface and solid rock. It would be seen how irregularly these were placed, and how frequently below clay, murum, and hard silty clay, all firm enough materials to found on, considerable depths of sand were met, this being especially noticeable in the Cheyair river. These showed the necessity and importance of having accurate sections to enable suitable spans and foundations to be designed, but the making of trustworthy borings to such great depths was by no means easy; those for the sections referred to were made by a professional English borer sent to Madras for the purpose.

Mr. Stoney.

With reference to the concluding portion of Sir Douglas Fox's remarks on the Madras Railway, during the construction of large bridges over sandy rivers, a temporary road laid on the river-bed had always been used for ballast and material trains, and also for public traffic while the bridges damaged by the floods described were being repaired. A line laid on the bed of the Huggeri river situated on the railway connecting Gundacul with Bellary, a large military station, carried the traffic safely for some four years while a permanent bridge was being built, with but few interruptions during the rains, when passengers and their luggage were taken across in boats to trains on each side. He thought that Indian branch lines could very well be carried cheaply across rivers on causeways, having their tops close to the river-bed. There was a very interesting low-level bridge over the Mahi river on the Anand Godra branch of the Bombay and Baroda Railway, designed by Mr. C. J. B. Hargrave, M. Inst. C.E., to carry trains at all times except during floods. These passed over as well as through the structure, which consisted of 64 openings 30 feet wide, spanned by 16 sets of plate girders 4 feet deep, and 8 feet apart inside, each continuous over four openings, firmly fixed by anchor bolts to masonry piers 5 feet thick at the top, with battering sides founded in the rocky bed of the river. The rails were laid on longitudinal timbers bolted to cross-girders 6 feet 6 inches apart, riveted to the lower flanges of the main girders, so that the tops of these rose above and protected the permanent way, the lower side of the girders being about 7 feet above the river-bed. Floods rising to as much as 14 feet above the girder-tops had, it was understood, passed over this bridge without injuring it, and traffic was seldom interrupted, and then only for a day or two; and he thought this remarkable bridge a very suitable type for use on branch lines in tropical countries, especially where rock foundations could be obtained at a shallow depth.

In reply to Mr. G. J. Symons he desired to point out that the second part of the Paper, as he had stated therein, was but a brief summary of great floods on the South Indian Railway, the facts recorded being given to enable engineers to form an idea of the extent and widespread destruction of works caused by such floods, and the rainfall table in connection therewith showed how great this was in short periods, and how widespread; to enter fully into this matter alone would need a Paper with suitable maps. Mr. Symons appeared to have missed the point he desired to emphasise, *i.e.*, that extraordinary floods, such as those described,

Mr. Stoney. were not due to exceptional local rainfall, in one monsoon only, but were caused by the occurrence of heavy rains over catchment areas in two succeeding monsoons. Heavy rains in October, such as those instanced by Mr. Symons especially when local, succeeding a light south-west monsoon, would not cause such floods, as lighter and more widely spread north-east monsoon rains following a heavy south-west monsoon, which had filled all tanks and saturated the soil. Plate girders, 140 feet long 4 feet deep, each continuous over two 64-foot openings, had been used very extensively for all the larger bridges on the Madras Railway. He had erected about 2 miles in length of these, and agreed with all that Sir Bradford Leslie said in their favour; no failure had occurred owing to their use, and they could be erected and riveted on the banks behind abutments, and put in place rapidly and cheaply without the use of staging, by rolling them over their piers irrespective of the occurrence of floods. In several instances of destruction of piers by floods, these continuous girders spanned a double opening, or overhung one span, according as an intermediate or end pier failed, thus greatly facilitating repairs, and the speedy restoration of traffic over the injured bridges. The old bridges of the Madras Railway with shallow foundations were cheap structures, being built at less than one-third the cost of the modern structures founded on rock which replaced them. He regretted the absence of information as to the capacity of the tanks which burst in the several river basins; dividing the calculated discharges given in the Table, p. 70, by the catchment areas, the following results were obtained:—Cheyair 47, Papaghni 97, Chittravati 47, Penner 27 and 34 cubic feet per second per square mile respectively, from which it would be seen that the discharge of the Papaghni per square mile was more than double that of any of the other rivers—a result which rather surprised him, and he agreed with Colonel Pennycuick that it was most difficult, if not impossible, to calculate the high flood-discharge of such rivers as those under discussion with any degree of accuracy. Those given were calculated thus: the hydraulic mean depth of each of three cross sections was ascertained, the average of these being taken as the hydraulic mean depth. Similarly the average area of the three was taken as the mean cross sectional area, the fall of the river-bed being taken between the extreme sections. The velocity was then calculated from these data by Dwyer's, Rankine's, Bazin's, and Du Buat's formulas, and the average of these was taken as the mean velocity, which, multiplied by the mean cross sectional

area at maximum flood-level, was taken as the flood-discharge. The results obtained could only be approximate in the case of such wide and shallow sections as those of the Cheyair, Figs. 6, ranging from $1\frac{1}{2}$ to $3\frac{1}{2}$ miles wide, and Papaghni, Figs. 8, with a width between 75 chains and 2 miles $26\frac{1}{2}$ chains; as in these cases it was probable that the shallow water forming the spill on each side of the normal channel would move forward very slowly, so that calculations made from such sections would give, most likely, too high results. The flood cross sections of the Chittravati and Penner were much more favourable, being well-defined, especially those of the latter, *Figs. 13.* He was unable to answer Mr. Horace Bell's question, why through instead of deck spans were used for the new bridges over the Papaghni, Chittravati, and Penner rivers, as these were designed by Messrs. Hawkshaw and Hayter. He was obliged to Mr. J. R. Bell for pointing out that the area described in the Paper lay within a cyclonic zone, and the way and works of the Madras railway, especially minor bridges, had frequently suffered much local damage, owing to cyclonic rainfall, the effects of which it was quite impossible to foresee or provide for. He agreed with Sir Guilford Molesworth in advocating the use of loose stone protection round the piers of large bridges, and in thinking that such protection was better placed immediately round such piers than spread out as a floor, especially if the piers were deep. Mr. Stoney.

Correspondence.

Mr. JOHN HOPKINSON thought it might be of interest to compare the rainfall which caused the floods of 1874 and 1884, described in the Paper, with the mean and extreme fall at Madras during a long period. In Dr. Blanford's "Rainfall of India," which formed Vol. iii. of the Indian Meteorological Memoirs, there was a Table giving the monthly and annual rainfall recorded at the Madras Royal Observatory for the long period of 74 years (1813–1886), including the years in which these floods occurred. An analysis of this Table, showing the mean, the maximum, and the minimum rainfall during this period was given in Table I. It would be seen that the rainfall of 33·49 inches at Madras in November, 1884, was an exceptionally heavy one, being the largest fall for November in the 74 years 1813–86; but it was not the largest fall which occurred in any month, for 37·73 inches fell in October, 1857. The flood of October, 1874, was caused by Mr. Hopkinson.