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 1½ to 3½ miles wide, and Papaghni, Figs. 8, with a width between 75 chains and 2 miles 26½ 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.

Mr. Hopkinson.

TABLE I.—RAINFALL AT THE ROYAL OBSERVATORY, MADRAS, 1813–1886.
Latitude, 13° 4′ N.; longitude, 80° 14′ E.; height above sea-level, 22 feet.

Period.	Mean, 1813–86.	Maximum.	Year.	Minimum.	Year.
	Inches.	Inches.		Inches.	
January	0·95	8·60	1827	0·00	23 years.
February . . .	0·29	6·28	1873	0·00	51 ,,
March	0·41	6·75	1820	0·00	45 ,,
April	0·64	6·38	1848	0·00	34 ,,
May	2·24	23·30	1827	0·00	17 ,,
June	2·09	8·63	1870	0·00	2 ,,
July	3·79	11·75	1818	0·25	1824
August	4·43	9·71	1847	0·83	1813
September . . .	4·71	14·89	1819	0·48	1824
October	10·81	37·73	1857	0·83	1826
November . . .	13·75	33·49	1884	0·90	1823
December . . .	5·15	22·81	1844	0·00	5 years
One year . . .	49·26	88·41	1827	18·45	1832

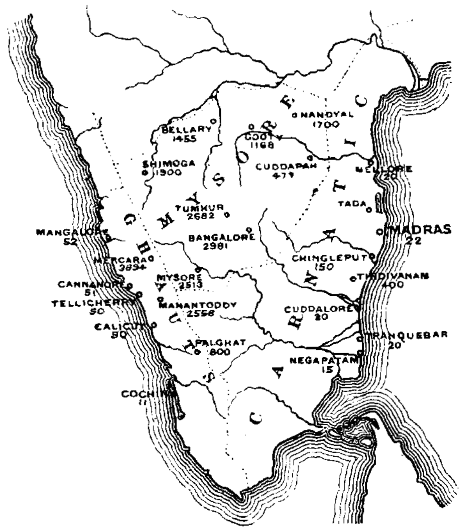
a fall of rain which at Madras was only 21·26 inches for the month. This had been exceeded twenty-four times in the 74 years, as was shown in Table II. Once this happened in May,

TABLE II.—RAINFALL EXCEEDING 21·26 INCHES IN ONE MONTH AT THE ROYAL OBSERVATORY, MADRAS, 1813–1886.

Year.	Month.	Inches.	Year.	Month.	Inches.
1813	November	28·18	1846	October	30·59
1815	,,	33·18	1851	November	24·85
1817	,,	24·33	1857	October	37·73
1818	,,	25·63	1858	November	22·12
1822	,,	21·40	1870	October	23·04
1826	,,	26·03	1871	November	26·41
1827	May	23·30	1872	,,	28·98
,,	November	22·12	1880	,,	22·97
1838	,,	21·89	1882	,,	29·25
1839	,,	21·27	1883	October	22·18
1840	,,	27·25	1884	November	33·49
1844	December	22·81	1885	,,	21·60

four times in October, eighteen times in November, and once in December. Floods were therefore most likely to occur, in the neighbourhood of Madras, in November; but they would appear to be almost as likely to occur in May as in December. Perhaps the most remarkable feature in these Tables was the fall of 23·3 inches of rain in May, 1827—the month of May having an average fall of only 2·24 inches, and in 17 years out of the 74 years having had no rain at all. But the effect of a heavy rainfall in May would not be so great as in December, for May was in the midst of a dry season while December was at the end of a wet one, when the ground might be thoroughly saturated. Taking into consideration the daily falls of rain, it appeared from the Paper that the greatest fall at Madras in any one day in October, 1874, was 7·47 inches on the 24th. This was not by any means an exceptionally heavy fall there, and even the greatest rainfall recorded in November, 1884, in the whole district under consideration, of 13·3 inches at Pauroti on the 7th, and the greatest in December, 1884, of 15·4 inches at Cuddalore on the 19th, had been exceeded at Madras. In the 74 years falls of rain exceeding that of the 24th of October, 1874, had occurred at Madras at least sixteen times, and in May, 1811, 16·38 inches were recorded. This statement was taken from a letter giving heavy falls of rain in 24 hours recorded at the Royal Observatory, Madras.[1] The sixteen heavy falls in the period of 74 years were given in Table III. But the rainfall of Madras did not well represent Mr. Hopkinson

Fig. 15.



MAP OF SOUTHERN INDIA, SHOWING THE THREE RAINFALL PROVINCES.

TABLE III.—HEAVY FALLS OF RAIN IN 24 HOURS AT THE ROYAL OBSERVATORY, MADRAS, 1813–1886.

Year.	Day.	Inches.	Year.	Day.	Inches.
1813	November 3	7·90	1836	November 27	7·77
1815	,, 28	8·63	1846	October 21	20·58
1819	September 12	10·00	1851	May 4	11·45
1820	May 9	11·12	,,	November 4	7·90
1822	November 4	7·83	1857	October 24	18·04
1825	October 29	8·88	1864	November 18	9·35
1827	May 9	12·08	1866	December 5	7·99
1836	November 20	9·65	1872	May 18	13·01

[1] Meteorological Magazine, vol. xxv. p. 153.

Mr. Hopkinson. TABLE IV.—RAINFALL OF OCTOBER, 1874, AND NOVEMBER, 1884, COMPARED WITH THAT OF OTHER WET MONTHS IN SOUTH-EASTERN INDIA (THE CARNATIC).

—	October, 1874.	November, 1884.	November, 1871.	November, 1872.	November, 1880.
	Inches.	Inches.	Inches.	Inches.	Inches.
Nellore	13·23	28·25	22·05	12·48	30·53
Tada	18·84	31·05	33·45	21·16	27·70
Madras	21·26	33·49	26·41	28·98	22·97
Chingleput . . .	14·75	30·40	19·22	25·84	12·51
Tindivanam . . .	16·90	25·36	18·55	26·35	20·10
Cuddalore . . .	5·00	44·08	18·86	32·48	24·82
Tranquebar . . .	7·90	36·51	19·00	24·05	23·30
Negapatam . . .	7·47	36·85	18·46	20·87	33·13
Mean . . .	13·17	33·25	22·00	24·03	24·38

TABLE V.—RAINFALL OF OCTOBER, 1874, AND NOVEMBER, 1884, COMPARED WITH THAT OF OTHER WET MONTHS IN SOUTH-CENTRAL INDIA (BELLARY AND MYSORE).

—	October, 1874.	November, 1884.	October, 1870.	September, 1874.	August, 1878.
	Inches.	Inches.	Inches.	Inches.	Inches.
Nandyal	9·65	1·82	6·00	36·80	16·55
Bellary	7·12	0·64	3·40	5·22	2·90
Gooty	11·52	0·97	5·05	11·65	10·05
Cuddapah . . .	11·85	9·15	13·17	30·55	11·43
Shimoga	6·77	1·55	9·47	6·35	6·28
Tumkur	15·22	2·11	20·89	19·31	17·03
Bangalore . . .	6·52	2·97	12·98	16·00	11·37
Mysore	4·96	1·08	6·49	3·56	4·08
Mean . . .	9·20	2·54	9·68	16·18	9·96

TABLE VI.—RAINFALL OF OCTOBER, 1874, AND NOVEMBER, 1884, COMPARED WITH THAT OF OTHER WET MONTHS IN SOUTH-WESTERN INDIA (MALABAR AND THE GHAUTS).

—	October, 1874.	November, 1884.	June, 1868.	July, 1882.	June, 1885.
	Inches.	Inches.	Inches.	Inches.	Inches.
Mangalore . . .	12·72	2·18	69·89	58·75	42·20
Mercara	6·39	2·69	30·98	101·64	42·07
Cannanore . . .	3·65	3·95	85·51	56·55	53·74
Tellicherry . . .	6·43	3·00	65·48	61·91	57·90
Manantoddy . .	6·43	2·96	15·50	84·68	31·78
Calicut	16·10	7·47	60·44	39·50	52·67
Palghat	4·78	1·43	21·39	37·67	20·35
Cochin	15·33	7·59	47·61	44·29	43·02
Mean . . .	9·20	3·91	49·60	60·62	42·97

the rainfall of Southern India. The variations in the rainfall over this vast area were very great. In Dr. Blanford's Memoir, already referred to, the South of India was divided into three rainfall provinces, *Fig. 15*—the Carnatic in the south-east, the great central plateau of Bellary and Mysore, and Malabar and the Ghauts in the south-west. The rainfall of Madras was fairly characteristic of that of the Carnatic region; but in the central plateau there was much less rain, and on the west coast there was very much more, and the heavy rainfalls occurred at an earlier time in the year, as the Tables IV, V, and VI showed. The rainfall of three wet months in the 20 years 1867–1886 was given in these Tables side by side with that of October, 1874, and November, 1884, at eight rainfall stations in each of the three provinces. It appeared that the rainfall of November, 1884, was much the greatest in this period in the Carnatic province, and that the fall of October, 1874, ranked amongst the heavy rainfalls in the central province, but that in no other case was the rainfall in either of these months at all exceptional. Much the wettest months on the south-west were June and July, the rainfall at one station (Mercara) in July, 1882, having exceeded 100 inches, or three times as much as that at Madras, which caused the great flood of November, 1884, while 50 inches to 60 inches frequently fall in June. Mr. Hopkinson.

Mr. J. R. Mosse remarked that on the 12th February, 1865, an unusual quantity of rain fell in Mauritius which destroyed, more or less, the roads and bridges throughout the island and inundated the lower part of the town of Port Louis to a depth of between 3 feet and 6 feet. The rainfall was general over the island, the minimum recorded in the 24 hours from the 12th to the 13th February, 1865, being 4·87 inches, the maximum 18·30 inches, and the mean of the fifteen stations was 9·86 inches. A rainfall exceeding the above, although causing less damage, occurred from the 11th to the 17th February, 1861, when 99 inches fell during six days at Vacoas [1] (1,200 feet above the sea), in Mauritius, equal to 16·5 inches per day. In April, 1870, 24 inches of rain fell at Cluny, in Mauritius, in as many hours, some of which fell at the rate of 4 inches per hour; and again at Vacoas, in January, 1871, 20 inches of rain fell in 24 hours. In September, 1872, a rainfall averaging 8 inches per day for four consecutive days fell in the up-country of Ceylon, and produced a flood which covered some 700 square miles of the low country near Colombo.[2] Mr. Mosse.

[1] Report of British Association, 1867, p. 120.
[2] Report of Flood Commission, Sessional Papers, 17th February, 1873.

Mr. Mosse. The Kalani river rose so high that the natives living on its borders had to take refuge in the cocoanut trees, and for a distance of several miles great damage was done to the embankments and bridges both on the road and on the railway from Colombo to Kandy. Where the road from Colombo to Ratnapura passed on a 6-foot embankment alongside the Kalani river, posts standing 5 feet above the road were put on each side so as to mark it out during floods, and a canoe used to be chained to every native's house in this neighbourhood. A small bridge consisting of five spans of 25 feet each had been built by the old Ceylon Railway Company about 2¼ miles from Colombo. The abutments of this bridge were partly washed away by the flood of 1872; but the piers, composed of screw-piles 16 inches in diameter, were found to be plumb and appeared to be uninjured, and a locomotive, weighing about 17 tons, which brought up materials for the repairs of the abutments, passed several times daily over this bridge. On the completion of these repairs, and before the passenger trains were run, an ordinary locomotive, weighing some 30 tons, was sent over the bridge; one of the screw piles then sank, the bridge broke, the engine fell into the water, and the driver and fireman died from the accident. It was subsequently found that the flood had scoured out a depth of some 45 feet. This circumstance was mentioned to show the treacherous character of screw piles. Since the Kandy Railway fell into the hands of the Ceylon Government, the waterway for some 40 miles from Colombo had been about doubled, and the piers of bridges had been constructed of cast-iron cylinders 6 feet in diameter filled with cement concrete. The records kept by the Director of Public Works and the Surveyor-General of Ceylon showed that a rainfall of 12 inches in 24 hours occurred nearly yearly in some part of that island either during the south-west or the north-east monsoon. From the 24th to the 27th June, 1888, 45·89 inches of rain fell near Hatton, in Ceylon, averaging 11·47 inches per day, and on the 9th August, 1886, 21·5 inches fell at Nawalapitya, Ceylon, in 24 hours. From July to October, 1882, 137·58 inches fell at Dimbula, Ceylon (4,300 feet above the sea), in 102 days—equal to 1·35 inches per day. The maximum annual rainfall in Ceylon was at Padupola, where the south-west monsoon first met the hill country. In 1871 the rainfall reached 280 inches, and in September, 1872, 18·80 inches of rain fell at this place in 24 hours. The mean rainfall at Padupola during nine years was 224·25 inches per annum. These rainfalls, especially when the ground had been previously saturated by the monsoons, necessitated extraordinary provision for waterways of bridges and culverts.

Mr. Mosse.

Great difficulty was experienced in obtaining reliable information as to flood-levels in Ceylon as well as in India, especially as rivers frequently rose 20 feet or 30 feet in as many hours. With reference to the changes in the channels of rivers, it was reported[1] that in August, 1875, the Goalundo Station on the Eastern Bengal Railway was removed to prevent its destruction by the Ganges, which it was seen would cut through the protective works; and in January, 1876, there was a depth of 30 feet of water over the spot where the station formerly stood. In May, 1871, Colonel P. O'Connell reported to the Government of the Punjab that "during the last inundation the Indus abandoned a portion of its old bed, and formed an entirely new channel about 16 miles in length. This new channel had cut away half of the village of Tundea-Nazibut, which was said to be 100 years old, and was distant from last year's channel 4½ miles." When Colonel O'Connell "passed along the new channel in April, 1871, the whole of the water of the river was flowing through it, the lower end of the old channel was silted up and nearly dry." That the current of Indian rivers in floods frequently ran "across the stream," that is to say, parallel to the bridge, was well known. It was reported to have done so both at the Jhelum Bridge and at the Empress Bridge over the Sutlej,[2] and hence the greater strength and safety of building the piers of these bridges in a circular instead of an oblong form. Most of the ancient tanks in Ceylon, many of which were constructed between 500 B.C. and 500 A.D., appeared to have been destroyed owing to the waste-weirs being insufficient to carry off floods. The Public Works Department in repairing these and constructing new tanks, made the banks 6 feet to 8 feet above the level of the waste-weir, and it then became necessary to provide such a width of waste-weir that with water flowing not more than 2 feet in depth over it, the weir would discharge a rainfall of 1 inch per hour. This quantity equals 60½ cubic feet per acre per minute, and as with water flowing 2 feet in depth 1 foot width of weir would discharge 605 cubic feet per minute, it followed that 1 foot width of weir would suffice for a rainfall of 1 inch per hour on 10 acres, which gave 10 feet of weir per 100 acres of watershed. Although this width was about three times that considered necessary by the late Sir Robert Rawlinson[3] for waste-weirs in England, it was not out of proportion to the excessive rainfall in the tropics as compared with that in England.

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[1] Report on Indian Railways by Sir Juland Danvers, 1875.
[2] Minutes of Proceedings Inst. C.E., vol. liv. p. 99; vol. lxv. p. 243.
[3] *Ibid*, vol. lxxiv. p. 166.

Lieut.-Gen. John Mullins.

Lieut.-General JOHN MULLINS, R.E., considered the Author had not exaggerated the difficulties with which railway engineers had to deal in India in providing for the passage across the line of the very great volumes of water which, at intervals of a greater or less number of years, were sure to be discharged. Tanks or storage reservoirs, often on a very large scale, and especially chains of tanks one above another in the same valley, were undoubtedly a cause of serious danger to a railway crossing the valley lower down; and it might be impossible to adequately guard against accidents to a line of railway so circumstanced when rainstorms of exceptional severity occurred, leading to the breaching of the tanks in succession and the consequent rush of all the stored water down the valley within a very short time. Probably the best that could be done was to determine where the damage, if any, to the railway should be located. The provision of waterway by bridges, culverts, &c., might be on a scale very liberal with regard to ordinary requirements and to the area of the basin drained, but it might be quite unable to dispose of accumulated flood-water. In the interests of the prevention of undue stress on the masonry works, of the limitation of damage to embankments, and of the prevention of breaches in these near masonry works, it was desirable to see where the breaching of the line, when the flood-waters had risen to a level above which it was of moment that they should not go, would do the least harm and still afford adequate vent. On the South Indian Railway, at any rate as regards that part of the line which ran parallel to the coast and at no great distance from it, the circumstances were somewhat different. Extraordinary floods were there due to cyclonic rainfall, sometimes of extreme intensity. The waterways of the rivers and streams were at such times but a small fraction of that necessary to pass the drainage. In the natural and unmodified condition of the country the whole of the latter, with the exception of abnormally high ground, of small extent and often occupied as village sites, was available for getting rid of the water, which passed away to the sea without causing more than temporary inconvenience. When, however, a railway came to be constructed, with its rail-level designed to be well above flood-level, the circumstances were entirely changed. Every defined waterway might be amply provided for in the bridges and culverts constructed, but the great auxiliary waterway, over the surface of the country generally, was blocked. For many years all might go well. When, however, a cyclonic downpour took place, it might be found that even four or five times the waterway provided

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would not suffice; and not only were bridges demolished or their superstructures literally swept away, as at the Karanguli and Gingee bridges, by the floods going right over them and accumulating against the girders quantities of driftwood and refuse, though the masonry remained firm, but widespread damage was caused to embankments, ballast, and permanent way. Such being the circumstances, it was very doubtful whether at any cost complete security for a railway could be ensured by arrangements intended to pass all the floods under the line. On the other hand, all but trifling damage could be prevented by passing a large part of extraordinary floods over the line, were the rail-level, wherever the conditions were as had been described, placed but very slightly above the natural ground-level. Of course, it was essential to offer so little obstruction to the flow of the water as to avoid all risk of any considerable action on the ballast, on which the immobility of sleepers and rails depended, and the ballast, of course, must be suitable to the position and protected by revetments or otherwise. No doubt such an arrangement would be considered imperfect, but the result would be the saving of much money with less rather than greater interference with the regularity of the train service. In years of ordinary, though still tropical, rainfall all the drainage would be passed under the railway. Similar arrangements to those above suggested had been adopted in the Kistna Delta, at the Commamur Canal, an important navigation and irrigation canal several miles in length, which traversed a tract of country particularly liable to cyclonic rainfall, at which times the country became a vast shallow sheet of water flowing with but small velocity towards the sea. Before the water-level of the canal was made almost the same as the ground-level, and the banks, which formerly existed at heights varying between 3 feet or 4 feet and 9 feet or 10 feet above the ground surface, were entirely removed, great damage was periodically sustained, and the canal was entirely silted up for considerable lengths. Now floods passed over it unobstructed and no damage was done, and the navigation suffered no inconvenience beyond that due to short delays. With regard to obtaining evidence of the levels attained by great floods in past years, there was no doubt great difficulty in securing reliable data with respect to floods which occurred more than 40 years or 50 years ago. Nevertheless, probably as good evidence was obtainable in India as in most countries, because in times of great floods the inhabitants had to seek safety in certain exceptionally high places; and, indeed, the village sites were often selected chiefly with a view to safety in

Lieut.-Gen. John Mullins. times of flood, and the points at such high places to which the flood-water reached were usually well known. The information thus obtained might be quite accurate, and when subsequent floods attained a much higher level it was sometimes assumed that there was radical error in the record of the old floods. It might be, however, that the augmented flood-level was attributable in great part to the works carried out, by which a large portion of the formerly existing waterway for disposing of flood-waters had been obstructed. It was not only railway embankments which so altered the conditions of flood discharge, for roads and canals were alike responsible wherever these crossed the drainage and ignored the part played by the country intervening between the defined waterways, in disposing of flood-waters. There were two ways of securing the safety of bridges across such rivers as those on the north-west line of the Madras Railway, which the Author had described:—(1) by building them on shallow but protected foundations, and (2) by carrying the foundations down to rock or to other hard material at a depth beyond that to which scour could extend. The bridges, the failure of which the Author noticed, had shallow, unprotected foundations, and that they failed was not surprising; for it was quite possible for scour in the beds of such rivers, due to deflected and conflicting currents, to go down to depths three times or four times greater than that at which the foundations were originally laid. Had the bridges been built with masonry floors, extending to, say, 12 feet beyond the upstream cutwaters and to double that distance beyond the downstream cutwaters, with curtain walls at both edges, say, 9 feet deep upstream, and the same depth as the pier foundations at the other edge; and had those walls been protected by dry-stone aprons about 15 feet wide beyond the upstream edge of the floor and 30 feet to 35 feet beyond the downstream edge, the thickness of the aprons averaging about 4 feet in the former and 4½ feet in the latter position—it might be pretty safely assumed that they would have remained unharmed so long as the floors and aprons were kept in good order. This arrangement was not applicable to bridges with screw-pile piers, but these could be effectually protected by floors and aprons of dry stone only. The best arrangement or design for a bridge depended upon locality and circumstances; but if suitable stone were cheap and abundant, and if, during a considerable part of the year, the river-bed had but little visible water, it was probable that shallow, protected foundations would be found much more economical than foundations carried down to rock or other reliable material when

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this was not reached within 35 feet to 40 feet below the surface of the river-bed. The bridges substituted for those so extensively damaged were fine structures, and were no doubt as stable as could be desired, but they were necessarily costly, perhaps more so than the circumstances of their sites rendered requisite. The Author had admirably carried out his duties in connection with the construction of these bridges, and his care and skill secured their completion at a less cost than was anticipated. His remarks were intended therefore in no way to detract from the merits of the design and execution of these bridges, but rather to suggest to engineers who might be concerned with similar works in Southern India in future, that it might be well in the interests of economy to consider whether it was possible to obtain security with the materials available near at hand and at a much less cost than by the use of iron cylinders.

Mr. Pownall

Mr. C. A. W. POWNALL observed that in Japan the railways ran, almost in all cases, parallel to the coast, and therefore at right-angles to the rivers discharging into the Pacific. The rain ran rapidly down to the plains from the central range of mountains in the main island, carrying silt and debris in suspension. So soon, however, as it reached the level plains the velocity of the current diminished, and consequently all such matter was precipitated. This process, continued for ages, with the river channels confined by banks which were continually being added to, had through Central Japan raised the rivers above the plains to such an extent that, in many cases, the railways had been taken, not over the rivers, but under them in tunnels. From the rivers thus elevated an enormous volume of water descended into the plains, when a flood succeeded in making a breach in the river bank. In a flood so caused in 1888, the water from the River Ibi poured down into the plains near Gifu with such violence as to cant up the ends of the sleepers, first slightly, and then each in succession more and more; so that after some had been set up on end those that followed were actually overturned, and for some hundred yards they were upside down and lying above the rails, the continuity of which was unbroken as the fish-plates held together; then the same effect in a reversed form was seen beyond this place of maximum pressure, and on passing out of the flooded area the line gradually assumed its normal condition. When constructing railways across plains subject to floods of this description, Mr. Pownall kept the formation level down to within 2 feet or 3 feet of the surface of the country, so that the great floods, due to the mountain rainfall when that escaped from the river-beds, Mr. Pownall. would pass over the line without having much besides the ballast to wash away, while the low bank was sufficient to let the rain which fell on the plains themselves pass underneath it. This was to make a distinction between the rainfall from the mountains as it passed in the river-beds over the plains *en route* to the sea, and the rain which fell on the plains themselves. The former was far the greater quantity, as the uncultivated land in Japan—chiefly consisting of the mountains—was as much as 88 per cent. of the whole surface of the country. The rainfall between June and September was usually very heavy. At Osaka 21·65 inches of rain were recorded in June, 1885, and the railway in that neighbourhood was submerged for miles, there being 3 feet of water over the Osaka platform. The few railway lines which passed through the mountains were severely tried by the summer rains. In 1895 a typhoon broke over the upper mouth of the Yamagase Tunnel, which was 1,478 yards long on a gradient of 1 in 40; and the flood tearing down this incline not only washed the ballast out of the tunnel, but broke the fish-plates and carried the rails bodily away. He believed that always when these tropical or sub-tropical floods were to be expected, the only course was to humour them and, in such cases as the plains of Japan, to let them pass over the railway, keeping that at a low level and exposing as little obstruction as possible to a force which was practically irresistible, and to the action of which, therefore, as little resistance as possible should be offered.

Mr. Thomson. Mr. T. FRAME THOMSON noticed an apparent discrepancy between the calculated rates of maximum discharge through the bridges referred to in the Paper, and the flow which would be expected from the data given as to the rainfall in the respective gathering grounds. Four stations in the catchment area of the Cheyair were given at which the average rainfall during 6 days was at the rate of 115,000 cubic feet per second, and the maximum average during 24 hours was 258,000 cubic feet per second. The averages over so many hours being so high, it seemed difficult to comprehend that there should not have been for short periods discharges from the basin at rates much in excess of the 98,481 feet per second, calculated from the fall of the river at the bridge. In the case of the Papaghni, the average for 6 days was 117,000 cubic feet per second and the maximum average for 24 hours was 265,000 cubic feet per second. In this instance the flood discharge was calculated at 243,454 cubic feet per second, approximating to the maximum 24-hour average. The data for the rainfall in the latter case were from two stations only. It would be interesting to learn from the Author whether, in calculating the flood discharge, any allowance was made for the abnormal increase of channel section due to the flow of the river-bed. It was generally believed that the river-bed was in motion to a very great depth, so much so that to this cause was attributed the complete disappearance of a passenger train which ran over a bridge of which part had been washed away, no trace of any part of the train or its passengers having been discovered below the point where it was lost after the floods subsided. If such motion of the river-bed took place to anything like the extent currently believed, all calculations of discharge based upon the normal channel section and fall must be received with the greatest caution, unless there were means of ascertaining and making a proper allowance for it. Mr. Thomson.

Mr. W. MARTIN WOOD thought much more than had yet been attempted remained to be done towards bridling these Indian inundations and conserving these floods, which, not only in the Madras Presidency, but elsewhere in the great peninsula, wasted their volumes in destruction instead of production. There was not a grander nor a more useful object than that of devising means to conserve and utilize the thousands of millions tons of water which yearly rolled uselessly and, as the Paper showed, destructively to the ocean on all the coasts of India. It was a mere excuse to raise objections, as the scare of varying rainfall or of occasional droughts. In India there were two great sources of water-supply. North of the Vindyhas the three great river systems, the Indus, the Ganges and the Brahmaputra, were fed from the snow and ice of higher Asia, and those never wholly failed. In Southern India dependence had to be placed on the rain brought by the south-west monsoon and the north-east wind. In this region irregularity of supply was to be counted upon, as Indian administrators knew too well. But it was just this adverse condition that civil engineers could redress; and this they could do to a far greater extent than had yet been realized. It might be permissible here to refer to that energetic and now venerable giant amongst hydraulic engineers, Sir Arthur Cotton. True, the work with which he was mainly identified was that of dealing with the deltas of the great rivers of South India; but his counsels and larger proposals were those that related to the upper side of water storage and utilization. For instance, that grand conception of the Tumbudra reservoir which, as had been pointed out, would conserve "10,000 millions cubic yards of water and provide for the distribution of four times as much, as it would be constantly supplied for seven months of the year, Mr. Wood.

Mr. Wood. thus commanding the whole Presidency," and would thereby protect the railways and much else. In Sir Arthur's words, "It was doubtful whether the whole world could offer another project equal to this." As bearing on this aspect of the subject, reference might be made to the Papers laid before the Society of Arts in 1891 by Colonel J. O. Hasted, R.E., and the discussions following on the Persian project (now completed), as recorded in the Society's Journal of the 27th May, 1891. With reference to one of the approximate causes of flood damage to railways, that of the breaching of reservoirs, it was mainly the smaller tanks that gave way (the *Kutcha* dams), but ordinary engineering skill could and did obviate that difficulty. There were in Colonel Hasted's Paper referred to, together with remarks by other engineers on that occasion, several observations bearing on the subsidiary branches of the subject apart from such technical skill and practical knowledge as was indicated in the Paper. It might prove of great value in encouraging other members of the Institution to study and to apply the economic and productive principles that invested the subject of hydraulic engineering with supreme importance in the great Indian peninsula.

Mr. Waring. Mr. F. J. WARING remarked that the beds of the rivers described in the Paper presented striking resemblances, and equally striking contrasts, to those crossed by the North-Western Railway of India, in the Punjab, between Delhi and Lahore. In both cases the upper strata were most unstable and specially liable to removal by scour in times of flood; but in the case of the rivers mentioned in the Paper, rock or material not likely to be scoured away was always found at a not excessive depth. Doubtless, with the appliances available when the bridges were originally built, these strata could not be reached except at a prohibitory cost, whereas, in the Punjab, he understood that borings carried down for several hundred feet failed to disclose the existence of any more stable strata than those through which the wells forming the piers had been sunk. As an instance of the rapidity with which scour occurred in these rivers in the Punjab, he might mention that when in charge of the maintenance of the bridge at Phillour, across the Sutlej, in 1871, he had soundings taken twice daily at each pier, and had found 20 feet in depth of the bed in one instance to be scoured away in less than 12 hours; but fortunately, during the following 12 hours, silting to an almost equal extent occurred. In such cases he considered that to mass stone around the piers, which he believed had been done with such marked success in the case of the Punjab rivers, was the only practicable

Mr. Waring.

protection. The Author had remarked that the current often flowed across the river and thus attacked the piers in flank. Mr. Waring had often noticed this in the case of the Punjab rivers, and he thought that, recognizing the possibility of this happening, the late Mr. G. P. Bidder, Past-President Inst. C.E., when Consulting Engineer to the Delhi Railway, had exercised a wise prevision in designing the piers circular in section and 12 feet 6 inches in diameter; as they would thus present an equal area to the current in whatever direction they might be exposed to it, and he was pleased to understand that Sir Bradford Leslie had advocated circular piers. Piers of this section were, however, only available generally for single-line bridges, as for a double line their diameter would be excessive, unless indeed the spans were of great size. Before leaving the question of floods in India, and the damage caused by them, he might mention that during the floods of 1871 a bridge of four 30-feet spans on the Delhi Railway, the abutments being of brickwork founded on wells sunk 20 feet deep, and the piers of screw-piles sunk to the same or a greater depth, was completely carried away during the night by a flood, a deep hole being scoured at the site. Mr. Waring had known the spot for several years previously, and had never observed more than a very sluggish flow of water, even at the time of high floods. At this place the Grand Trunk Road ran parallel to the railway and barely 10 chains distant on the up-stream side of it, the corresponding bridge on the road being a wooden piled structure. He attributed the disaster in this case to trees, brushwood and debris becoming entangled in the piles of the wooden road bridge, thus damming back the water until it had acquired sufficient head to carry away the road bridge and with it the railway bridge also. In some cases on the South Indian Railway, instead of providing bridges over streams, or rather watercourses where there was very seldom any flow of water, the plan had been adopted of laying the rails in the level of the bed of the stream and allowing the floods to pass over them. This, where the traffic was not very heavy, and where its interruption for a few days annually was not of great importance, was, he considered, a judicious economy, but the idea was not a new one, for in a Paper on the Sind Railway, by Mr. John Brunton, M. Inst. C.E.,[1] a description of the crossing of a plain (subject to floods, nearly 5 miles wide) in this manner was given. The local conditions did not frequently allow of costly bridges being in

[1] Minutes of Proceedings Inst. C.E., vol. xxvii. p. 468.

Mr. Waring. this manner dispensed with. Every engineer who had had tropical experience must be painfully and fully aware of the great damage caused by exceptional rainstorms and floods, and how difficult, if not indeed impossible, it was at all times to guard against it. He might mention two instances of exceptional rainfall in Ceylon coming within his own experience, in addition to those to which reference had been already made in the Proceedings. In April, 1891, at West Haputale, where previous records had given a maximum daily rainfall rarely exceeding 4 inches, 8 inches of rain fell in 4 hours; this, he thought, had been rarely equalled in so short a time. Again, at Pattipola, on the Haputale Railway, where careful records extending over 6 years had shown that the maximum daily rainfall was also not more than 4 inches, a rainstorm of 8·23 inches occurred on the 27th December, 1895, which caused many slips and much damage to the railway. He thought that the Author would always retain a lively recollection of this storm, inasmuch as the train in which he was travelling narrowly escaped destruction.

Mr. Stoney. Mr. E. W. Stoney, in reply to the Correspondence, remarked that the Cheyair, Papaghni, Chittravati and Penner rivers, lay chiefly within the great central plateau, and that the destructive floods described in these occurred in October; while those on the South Indian Railway were in November and December, and were caused by heavy rains falling on ground previously saturated. He had already described how the discharges given by him had been calculated from the flood cross sections; no allowance was made for flow below the river-beds, there being no means of doing so. These sandy river-beds were found charged with water up to or near their surface, even in the dry season; so that it was reasonable to suppose that a considerable flow took place during floods below the normal river-bed, and that the sand was also moving—consequently calculations of discharge during high floods could at best be but very approximate. In high floods the waters also spilt over the river-banks, and flooded large areas of the adjoining country, which moderated and reduced the maximum discharge, and absorbed the surplus flow of the catchment area, to be passed off later as the river fell. He would always remember the storm of the 27th December, 1895, and Mr. Waring's kindness and hospitality to him and his fellow-passengers, who narrowly escaped being killed by the slipping in of a cutting upon a train in which they were travelling.