General Strachey, R.E., thought the Paper was exceedingly valuable, and explained extremely well the great work on which the Author had been engaged in Southern India. His experience had been confined almost entirely to Northern India, and there was very little he could usefully say on the engineering questions which were at issue. If, in the course of the discussion, reference was made to matters not of a specially engineering nature, but touching the general subject of irrigation in India, he would make such remarks as occurred to him.

Sir A. Cotton said he had had fifty years of Indian experience, and could speak with some authority on this subject. The Soonkêsala canal was a grand work on these grounds: First, it was a large work in the upper country. Irrigation works had been executed by the Government in the deltas of the rivers and in the interior plains, but they were very different in their nature from this, which was carried through a vast, rocky, undulating country with a great fall. In the next place, it was the first instance in India of a thoroughly well-projected and well-constructed system of steamboat canal 190 miles in length. Other navigable canals of considerable extent had been constructed, and the canals of the Godavery could be navigated by steam-vessels, but these were not so complete as they ought to be. Even in America there was no steamboat canal to this day. With respect to the projection and execution of this work, he had examined all the papers that had passed between the Government and the company. It was a matter of notoriety that there was a strong prejudice on the part of officials in India against enterprises of this kind, and the papers he had seen all bore the stamp of that feeling. It was therefore quite safe to consider that in those papers any mistake in projection or execution would be brought forward, and the tone of the papers could not be mistaken. Going through them, he never was more satisfied that there was no considerable mistake either in the projection or in the execution of these works, and that they were thoroughly effective. Numerous errors were pointed out, but they were mere trifles, not affecting in the slightest degree the real, fundamental points of the work. It was a great satisfaction to him to find that it was so. The feeling was, and had always been, exceedingly strong against private enterprise in India, and every effort had been made to suppress the present company. As a rule such works got entirely into the hands of the Government; but he considered it was extremely important that these works should be entrusted to private companies, for, if any questions arose, there was no appeal in the case of Government works. If the people thought themselves aggrieved in respect of the arrangements about water or the price, they appealed from the power which they considered treated them injuriously to that same power. They had no redress. This had been forced upon his attention repeatedly in India, because several times when he had tried to defend native rights, he had found it impossible to do so, for the authorities were the very persons they had to complain against; and he had been baffled again and again in that way. Now if a company sold the water, and the native considered himself aggrieved, of course he could appeal to the Government, and, what was more, the bias of the Government was always on the side of the native. The natives themselves were extremely sensible of this. He could not conceive what the feeling was against these works being in the hands of a company. This work now consisted of a canal 190 miles long, leading the water of the Toongabudra into the valley of the Pennêr, and by that river to the district of Nellore, where there was a vast extent of native works which had been improved by the Government, and which would receive any water that was not used on the line of the canal. The project was complete in itself in a certain sense. It would irrigate 250,000 acres of rice during the monsoon, and 750,000 acres of what was called dry-grains after the monsoon. Moreover, there were 190 miles of navigation to bring the produce down to a certain point. But two things were required in addition; first, the navigation should be completed from the end of the canal to the beginning of the Government canal at Nellore, a length of 80 miles. When that was done there would be water carriage from the head of the canal to Madras, about 400 miles. Without this the work would be in a certain sense imperfect; that was to say, at the end of the canal the produce would have to be delivered over to the railway, to be carried, at an expense it would not bear, to Madras. If, however, the water transit were completed, it would open the whole of this highly-irrigated country, not only to Madras with its 500,000 inhabitants, but also to all the markets of the world. Therefore he considered the first thing necessary to be done to complete the project was that line of water communication. The other requirement was to store water to keep the canal supplied for the five months during which the natural supply failed. Water could be stored economically all over the valleys of the Toonga and Budra, in quantities sufficient for an additional million of acres during the dry season. Those two works could be executed at prices which would greatly increase the general return of the whole project, though the works as they now stood were, in his opinion, abundantly secure of getting a large percentage upon the outlay.

A minor point he would allude to was the cost of making these canals navigable. In this case there was a gradient of 450 feet in 190 miles, or 2½ feet per mile, and the outlay had been £150 per foot of fall; therefore with 2½ feet fall per mile it was £375 per mile. In considering the expense of transit works in India he would refer to the grand standard, viz., the cost of the railways in that empire. This had amounted on the average to £20,000 a mile, while the cost for lockage on this interior canal was, as he had stated, about £375 per mile—an insignificant item in comparison.

There was now open in India an unbounded field of enterprise and employment for the Civil Engineers of England, and the Madras Irrigation and Canal Company had done sensible benefit to the country in thus opening their works, and he hoped they would be permitted to complete the whole project which he had sketched out.

Even in England, where the distances were comparatively insignificant, the cost of transit was an important question; but in India it was of vital importance, where materials or produce had to be conveyed 500 or 1,000 miles to reach markets and ports. As yet almost the whole of India was shut up from the want of cheap water carriage. The railways could not properly open up India. They were carrying goods at 2*d.* per ton per mile on an average, and this only by being backed up by a heavy annual subsidy from the Government, and that charge of 2*d.* a mile was, in fact, a complete failure. India could not be developed under such a system; it must have cheap transit. He wished generally to express his opinion on this subject as an officer of long experience and a Government official. In many respects he stood in a peculiar position with regard to these works. He neither projected them, nor had he anything to do with their execution; nor was he in any way connected with the Madras Irrigation and Canal Company. He spoke as an unbiassed individual; but he could not refrain from expressing his satisfaction at seeing this extensive work completed and brought into active operation.

Irrigation works in India were now projected, and all but two or three of them were in process of execution, which would be completed at a cost of 35 millions sterling in irrigation and navigation, so that there was really an extensive work going on in this essential point.

Mr. BATEMAN said there could be no question as to the great importance of this work, both as a work itself, and with respect to the advantages it must confer upon India; but he confessed to being somewhat surprised at the sections of the embankments. He was himself rather an old hand at making reservoir embankments; but he must say that he dare not construct reservoir banks in the way these canal banks appeared to have been constructed. Fig. 8, Plate 15, represented an embankment 30 feet in height with a wall 2 feet thick at the top, and not more than 6 feet thick at the bottom. He could not comprehend how that bank, even with the water in the canal, could stand at all. If it did, it was a new plan of engineering, and was something from which engineers might learn, and possibly copy, for the future. He was quite sure no railway engineer, much less an hydraulic engineer, would venture to build a wall 30 feet high, 2 feet or 2 feet 6 inches thick at the top, and 6 feet or so at the bottom, and expect it to stand.

Then, as to the masonry revetment (Fig. 9), founded on sand, with no protection or provision to prevent the water from the canal passing through into the bank; that wall, judging from the scale, could not be more than about 2 feet 6 inches thick, and again he could not understand how that stood. If it did, it was a valuable piece of experience in engineering. He would like to ask the Author what was the character of the sand on which that wall stood. If it were pure sand, a depth of water upon it of 30 feet would cause it to act simply as a filter, and the water would escape. If it were argillaceous matter, mixed with sand, it might be so made as to be impermeable to water, particularly if it were made by basket labour and padded over, as on the Continent. If so made then he could suppose an embankment might be formed without puddle but impervious to water. Still the material of a bank had a particular slope at which it would stand without thrust; all above that slope would exercise a pushing force or pressure from behind, and such a revetment wall supported as shown he should scarcely expect to stand.

Again, three sections (Figs. 15, 16, and 17, Plate 16) were recommended for adoption, as the mode in which every embankment should be formed, by puddle walling on the face or slope of the embankment, without this face puddle being tied into any material at the bottom or foot of the slope. The great difficulty in constructing water-tight banks in this country was the character of the ground on which the embankment had to be formed. With the right material, and with the materials properly put together, a water-tight embankment might readily be made; but there was great difficulty in preventing the escape of water below the embankment, through the natural ground on which it rested. If it were, though sandy, a water-tight and somewhat argillaceous mass of alluvial deposit, such as he could imagine would be found over a great portion of India, then there was not only a good material, but a material which could not, except by unskilful management, make a bad bank. If it were put together in thin layers, well trodden, it must inevitably make a water-tight mass, which would be safe. In this country where there were not such good materials, there was danger in putting puddle on the face of an embankment. The embankment, except it were made of sand, gravel, or stone, would gradually settle, the facing of puddle would crack, and the water would escape. These were his experiences; and he should be afraid to trust to less precaution than practice had taught him to adopt.

By way of illustrating how an embankment might be made perfectly safe, the Author had suggested an embankment 200 feet in height, through which the water should leak, but so as not to destroy it. Engineers usually endeavoured to construct banks water-tight in themselves, without any leakage. It was a new doctrine that embankments to be safe should be leaky, though he had known several cases of reservoirs so leaky that they were never filled, and consequently never washed away. But it did not answer to make leaky embankments. The ordinary filtering medium in this country was about 4 feet in thickness. The quantity which he understood the Author to say would filter through this embankment was 500 gallons per square yard: that would be little short of 60 gallons per square foot. He did not know in what time that would take place; but a good filter would allow 75 gallons per square foot to pass in twenty-four hours. The water to be filtered rested on fine sand, which was supported by a coarser medium of sand, and that again was supported by a coarser still, till it got to round boulders as large as turnips and potatoes. That filtration was carried on under only 1 foot or 2 feet of water pressure; or, in the case of the London Waterworks, 3 feet or 4 feet. Where the water was 200 feet deep, he should be sorry to contemplate the result in a work for which he was responsible. In making these remarks he did so only to elicit further information, as to the character of the material on which these banks were constructed, and of which they were made.

With regard to the masonry of the weirs, one of them appeared to have been placed upon red shale (Fig. 5, Plate 15). Now shale was not a durable material with water falling vertically upon it; and unless the masonry floor was very firmly fixed, the drop of the water from a height of 14 feet 6 inches would suck out that masonry sooner than it would in that weir which was of greater height, but was placed upon the much harder gneiss rock (Fig. 3). The safety of such a work depended entirely upon the character of the rock over which the water fell. As a rule, his experience was that a perpendicular face was not a judicious form for constructing a weir, and that unless the work was built on substantial rock, the foundation was liable to be injured. A sloping weir, which allowed the water to fall gradually to the foot, was a safer mode of construction. He should be glad to hear how the sand and gravel in these banks were put together. In some valleys in Spain in which he had constructed weirs, the material consisted of sand or gravel of such an argillaceous description that it was hardly possible to make a bad bank. But if the embankment was to be formed on ground not itself water-tight, and if it had to be raised 40 or 60 feet high, it required a large amount of skill and caution to secure a good foundation.

Mr. Robert C. Reid contended that an embankment wholly of earthwork and puddled clay would make a safer and more lasting structure than a composite one of masonry and earthwork. The method proposed by the Author for constructing embankments which could leak without detriment to their stability might be theoretically correct, as far as the bank above the natural surface was concerned, but it was difficult to see how such a structure could be tied into the ground on which it stood so as to be safe. The site for such a bank must be prepared, either by excavating the whole material under the base down to an impervious stratum, and rearranging it according to the plan adopted for the portion above the surface, or a puddle trench would have to be dug and filled with clay all round the inside toe of the bank, where the finest material was placed. In order that the embankment might act as a filter-bed, the different materials must shade into each other, from fine sand to rubble, by minute gradations, or else the sand would be blown by the water through the rubble; and the process of selecting the available materials, by riddling or otherwise, and placing them in their proper positions, would be very costly. Provided the gradations were perfect, the finer the particles at the inside, the less would be the leakage, and if they were very fine, as in clay, there would be no leakage at all. There would therefore be great varieties in the retentiveness of different embankments built in this manner, and indeed in different portions of the same embankment. It would be almost impossible to predetermine how much a given embankment would leak, and there would be no certainty of having sufficient command over the water in the reservoir, so as to regulate the supply from it.

As regarded the construction of water-tight embankments, the plan of placing the puddle wall along the inside slope was not so good, in Mr. Reid's opinion, as the vertical wall in the centre of the bank. More puddle would be required, since the area of the slope was greater than the vertical area, while the puddle trench having to be carried round the toe was longer than if it were in the centre line, and, in the event of settlement, the puddle if at the face, being inclined to the direction of subsidence, was more liable to crack than if it were in the line of subsidence, as it would be if vertical.

The proper function of the puddle wall in an embankment was to stop the 'creep' of water, which was inevitable in all earthwork unless wholly constructed of clay or other impervious material. Whenever water acted upon clay in any volume, with the slightest motion it disintegrated the particles. Now this was the condition in which the puddle would be in, if at the inner surface, with nothing but rubble and gravel between it and the water; for every wave in the reservoir would have its corresponding undulation in the water lying against the puddle wall, and would eventually in this manner eat into the clay. But, by placing the puddle wall in the centre, there was a great thickness of earth between it and the water, and the minute tubes which carried the water through the earthwork effectually retarded the action of waves in the centre, as well as prevented the direct pressure of the water on the puddle. If, however, the earthwork of the inner slope was of open, stony material, tipped in layers of 5 feet or 6 feet thick, and the stones were allowed to roll down to the bottom of each tip, it would not have the desired effect in protecting the puddle wall. Hence it was, that experienced engineers specified banks to be built in thin layers, with the most clayey portion of the material inside and next the puddle wall. On the outside slope the material next the wall should also be clayey, so that it might bear with the same effect as the inner slope on the wall, and keep it in equilibrium. The layers should also be sloped inwards to the centre, so that the beating and consolidating would tend to press the earth against the puddle wall with as great force as the water of the reservoir would when full. If the outside slope was not capable of exerting such a pressure through an infinitely small space, it could not sustain that pressure; and whenever the water rose, it would yield, the puddle wall would bend, and, having no elasticity, would crack and cause the destruction of the bank.

There was hardly any limit to the height an embankment might be raised, as far as its power of resisting the pressure of the water was concerned ; but the site on which it was built might not be able to carry the extra weight, and might bulge out above and below the bank. The slopes, which were sufficient for ordinary heights, would hardly be safe when the mass of artificial earth was increased to such an extent as was proposed.

Mr. A. J. Dodson, who had been engaged for eight years on this canal, said that, except the addition of a puddled foreshore, and the alteration of the outline of the bank in the rear of the masonry, the wall (Fig. 7), and the masonry revetment (Fig. 9), and all others of which they were types, were completed in the spring of 1865, and the puddle-core walls in the autumn of the same year. The length of canal in which the loftiest specimens of each kind occurred was opened for trial in 1866, without accident. The face walls (Fig. 8), 10,518 feet in total length, and the puddled banks (Fig. 10), were completed by Midsummer, 1868; water was passed down in July, and the canal navigated for 65 miles in August of that year, without doing them the slightest injury. A portion of ordinary bank, thrown up without selection, did, however, give way in that month.

Again, the walls represented in Fig. 7 were completed in 1865; no failure or accident occurred to these except during the extraordinary storm of August, 1870.[1] One wall in the 24th mile was then overtopped, and, as there was no protection to the bank overlying the ends of the wall, a breach occurred at the junction, carrying away about 100 feet of the bank, and something less of the wall. Another wall, in the 28th mile, of narrower section than that shown in Fig. 7, also gave way, for the length of a chain or two; and consequently all the length of the narrow section of wall—a few chains only, and no great height—had been since specially protected in the front and rear. Fig. 9 represented a masonry revetment completed in 1865, above 1 mile in length. No failure had occurred to this revetment beyond cracks, except during the storm of 1870, when it was overtopped by the water, and the bank washed away from behind, so that a breach followed 220 feet long in one place. The scour of the water towards the breach set against the toe of the revetment in another part, where

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxiii., p. 403.

a length of about 4 chains slipped into the canal, but no breach occurred there.

Puddle-core banks, Fig. 11, were liable to leak. One in the 30th mile, only 10 feet high, on fissured rock and gravel, had the lower part of its core washed out on the 29th of July, 1868. A puddle foreshore was then added, and no failure had since taken place. They were the least satisfactory, perhaps, of any of the sections, though they had never been breached. The banks shown in Figs. 8 and 10 had given no trouble, and they survived the storm of August, 1870.

The above mishaps were spread over a period of six years, and a distance of 65 miles. The first section was exposed to the action of river and land floods; the second, third, and fourth, to large waves on tanks, especially at Tongaduncha tank; in the fifth section land floods spread 5 miles against the upper banks 10 or 15 feet deep. It was to be remarked that the puddle was not of the best nature. It consisted of black cotton soil, which contained little clay. He thought the wonder was that with these difficulties there had not been even more accidents.

Mr. Latham had stated that 2 cubic yards per hour per acre was the datum on which his calculation of the amount of water for irrigation had been made. Colonel Cotton insisted on 1 cubic yard on the Cauvery and Colleroon irrigation works which he constructed; and Sir Arthur Cotton said that in the Tanjore and Godavery works $1\frac{1}{3}$rd cubic yard was sufficient, or 4,000 yards for the one hundred and twenty days of wet cultivation, and 1,500 cubic yards for dry crops. If that were the case the capabilities of this canal were far greater than those named in the Paper.

With regard to the navigation of the canal, the Author had stated what he imagined would be the amount of goods conveyed. That, however, would be only limited by the carrying power of the railway from Cuddapah to Madras, into which this canal now worked: but he was sure there would soon be a large amount of traffic in passengers. He had been up and down the Godavery canal, and he was astonished to see the amount of native passenger traffic from one place to another, in districts much less inhabited than those served by this canal. He confidently believed that both in an engineering and in a commercial point of view the Soonkêsala canal would prove to be a success.

Mr. G. H. Phipps observed that the particular point which interested him was, as to whether canals in India could be made to contribute largely to the means of intercommunication in that country. From the observations of Sir Arthur Cotton he appeared to be under the impression that railways, which he assumed had cost £20,000 a mile, could not do much more for intercommunication in India than irrigation canals. Mr. Phipps thought it might be well worth while, where such a canal as the present one, costing £8,000 or £9,000 per mile, had to be constructed, to render such a canal navigable, if it could be done, as stated in the Paper, at such a moderate additional outlay as £375 per mile. He could not, however, conceive the idea of canals superseding railways as a general mode of communication over large tracts of a country like India. Although not in all cases, yet in a great many, particularly in the transport of troops and military material, speed of transit was a very necessary element, and in this instance, not only would the canal be affected by the ordinary causes of slow travelling, but this evil would be increased by the current against which the return boats would always have to contend. Assuming, however, that railways, and not canals, were to afford the means of travelling in India, the great thing was to construct them cheaper, so as to cover more ground, and thus tend to increase the trade and prosperity of the country. Their cheapness would possess the further advantage of comparatively easy renewal after being swept away by the heavy floods so fatal to such works in India. He submitted that what was wanted for India was an extensive system of railways constructed upon a cheap plan, for he never could believe that navigable irrigation canals could form an adequate means of intercommunication in that country.

Mr. Bruce said, on some of the drawings banks 50 feet high were represented as having been built on sloping ground; while on the high side he understood there was hardly any bank at all. He did not see why it was necessary to make walls of that height, if by slightly moving the direction of the canal laterally this could have been avoided. He thought Sir Arthur Cotton had injured his advocacy of canals by contrasting them with railways, because in India both railways and canals were wanted. It had been asserted that it was proposed to make an extension of this canal at the rate of £375 per mile, that the Indian railways had cost on the average £20,000 a mile, and that the latter could only carry goods at 2*d.* per ton per mile, while the canals could carry goods a great deal cheaper; and that therefore, in the proportion of £20,000 to £375, railways were worse than canals, independently of the greater cost of carriage by the former: but the fact was this very canal had cost about £9,000 a mile.

Mr. Phipps remarked that Mr. Bruce was under a mistake. It had not been stated that the canal could be made for £375 per mile, but that that amount would render an irrigation canal navigable.

Mr. Bruce said, he understood that the extension to Nellore was to cost £375 per mile for navigation, while this canal cost nearly £9,000 per mile; but if the £375 was only to do a portion of the work of making the canal, so much the greater the unfairness of putting that in contrast with the entire cost of the railways. In the Presidency of Madras the railways had not cost £20,000 a mile, and this estimate of £375 per mile had been put against the cost of carrying the railway across the Ghâts, instead of taking the cost of the railways in the presidency, which he believed did not exceed £12,000 per mile in the case of the Madras railway, and in the Great Southern it was the same as this canal. Of course rolling stock was included in the case of the railways in that amount, not so in the canals.

Lieut.-Col. J. G. Medley, R.E., remarked on some points of detail in which this canal differed from those in the N.W. Provinces of India, that such comparisons were useful if only because the Engineers of Northern and Southern India had so little opportunity of seeing one another's works.

He should be glad to know if there were any masonry falls in the main canal, and if so, what form of fall had been fixed on? In Northern India, the vertical fall with a grating was now admitted to be the best yet devised. A cistern of water was sunk below the level of the lower bed, on to which the water fell as on an elastic cushion; while its force was also broken by its being first made to pass through a set of bars fixed obliquely in the crest of the fall, similar to the teeth of a comb. If there were no falls, the profile of the country must be very favourable, and the difficulties of navigation would be considerably lessened; but the combination of irrigation and navigation in the same canal involved difficulties which had never been successfully overcome in Upper India.

He inquired whether the under-sluices in the weirs placed across the main channel at the heads of the branch canals were found sufficient to prevent silting up? In the N. W. P. of India, regulating heads with wide sluices would be required across both channels at the points of bifurcation. He also asked whether the irrigation was all surface irrigation, or whether the water had to be lifted? And whether the water was delivered into the village water-courses from the main canal, or by intermediate distributaries? It was stated that measuring sluices were not needed. In the N. W. P. the difficulty had always been how to insure a constant discharge with a head of pressure continually varying; and though various attempts had been made to overcome this difficulty, they had been unsuccessful, owing chiefly to the flatness of the country preventing there being any spare fall beyond what was actually required for the flow of the water. Hence the water rate was always assessed on the area irrigated, instead of on the amount of water delivered—an objectionable method, as it led to waste of water, and to continual expense in measuring irrigated areas, besides opening the door to disputes and interference with the cultivator's arrangements.

With regard to the formation of the banks, it might be noted that the great embankments by which the Ganges canal was carried for 3 miles across the Solani valley, at an elevation of from 10 to 40 feet above the bed, were formed of earth, with a double revetment of brick masonry built in steps. These had stood well, and there was no leakage. Puddled banks, without further protection, would be perforated by rats in Northern India, and there was no stone or gravel to protect the puddle by pitching: brick was the only material available.

It was estimated by Mr. Latham that 2 cubic yards of water per hour were only sufficient to irrigate 1 acre of rice. This was only $\frac{1}{4}$th of the irrigating duty now obtained from canal water under favourable circumstances in the N. W. P. when applied to wheat, the great staple of Upper India. One cubic yard per hour would there irrigate 2 acres; or, to use N. W. P. nomenclature, 1 cubic foot per second would be thought fully equal to the irrigation of 267 acres of wheat, in any canal where the irrigation was fully developed. On the Eastern Jumna canal, the most perfect in this respect in Upper India, 306 acres were irrigated in 1868-9. On the Ganges canal, where the distributaries were not yet completed, only 232 acres.

Of course the amount of water required for rice was very different from what was wanted for wheat; and although there was some rice irrigation in Upper India, it was in the autumn, when there was plenty of water available; whereas the chief crop, or wheat, was watered in the cold weather, when water was most scarce and precious. The water-rate assumed in the Paper, Rs. 6 per acre, would seem very high in Northern India, where sugar was the only crop that paid as much as Rs. 5 per acre for surface irrigation (Rs. $3\frac{1}{3}$ only if the water had to be lifted). Rice paid Rs. 3 only, and wheat Rs. 2·4. For so large a discharge at the head of the canal as 400,000 cubic yards per hour, or very nearly 3,000 cubic feet per second, the length, 190 miles, seemed very small. This was the calculated discharge of the Baree Doab canal, which when completed would be 470 miles long; and this difference made it of little use to compare the cost of canals under such different circumstances as those of Northern and Southern India. He had roughly estimated the cost of an irrigation canal in Northern India at about Rs. 4,000 per cubic foot per second of calculated discharge, or Rs. 30,000 per mile of length. The Soonkêsala canal had apparently cost Rs. 50,000 per mile, or Rs. 3,330 per cubic foot per second.

Mr. BATEMAN said, the account of the failures which had taken place afforded some confirmation of the fears he entertained from looking at the sections of the embankments. With reference to the quantity of water required for irrigation, a cubic yard of water per acre per hour was equal to a depth of $\frac{1}{6}$th of an inch of water per day. In the south of Europe, in Valencia and Murcia in Spain for instance, where there were still many of the old Moorish irrigation canals at work, the ordinary irrigation amounted to $2\frac{1}{2}$ inches in depth, renewed every fortnight in certain periods of the year, which was about the same quantity as was used in this case, if put on the land once a fortnight instead of daily; but rice required four or five times as much water as the ordinary crops of the country, and for about ten weeks of the year.

Mr. REDMAN observed that the remarks upon the formation of the embankments, rather confirmed the propriety of the criticisms of Mr. Aird on a previous occasion,[1] as to the absence of puddle, when it was said that the method of construction by basket-work, by men, women and children, was such as to knead the material into a very compact mass, so that it became of the nature of a puddle bank, the slope of the bank being 2 to 1. In the Bann reservoirs, County Down, the slope in some cases was 3 to 1; on an average $2\frac{1}{2}$ to 1, with a puddle bank 10 feet in thickness.[2] In 1843 Mr. Thom rather curiously advocated the disuse of puddle for reservoir embankments, and described a peculiar arrangement of the laminæ of the banks.[3] It occurred to him that the reply to the objection of Mr. Aird, that no puddle was used, viz., that the entire mass was so trodden down and consolidated as to be of the nature of puddle, might apply to some extent to the criticism of Mr. Bateman in this case.

Mr. BATEMAN explained that it was not the embankments he objected to, but the revetment walls, as being made too light in section.

Mr. RUSSELL AITKEN did not think any advantage had been gained

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxiii., p. 410.
[2] *Vide* Ibid., vol. i. (1841), p. 169; and vol. vii., p. 256.
[3] *Vide* Ibid., vol. ii. (1843), p. 191.

by a departure from the old method of constructing earthen canal embankments, viz., a core of solid retentive earth, with a puddle trench in the centre of the bank to stop any leakage. Even in England there were serious objections to facing the slopes of embankments with puddle; and in India especially it was highly dangerous, because, when the puddle was not covered by water, the heat of the sun dried it up, and caused it to crack to a great depth. In India, too, vermin were a source of great annoyance and danger, and one bank of which he had charge was perforated by land crabs. Indeed it was almost impossible to keep vermin out without masonry when the puddle was near the surface of the bank. They forced their way through the loose stones, and he had no doubt the banks of the Soonkêsala canal would one day give a good deal of trouble from this cause. True, he had while in India successfully repaired one embankment by placing a puddle apron on the face of the embankment; but in order to prevent the heat of the sun and vermin injuring the puddle, he had covered it with pitching in Portland cement, through which vermin could not penetrate. The embankment was watered once a day to prevent it cracking.

He had some time since looked over Sir Arthur Cotton's writings, and he thought that officer's views would be very well represented by the following extract from one of them: "Several lines of railway have sealed up their tract of country probably for ever against cheap transit, and even against irrigation, for the railway men, must as it were for their lives resist irrigation works in the neighbourhood of their lines, as inevitably leading to cheap transit. . . . . If the 30 millions to be spent in railways become a real warning to us, and make us consider, whether proposed works are really suited to the circumstances of India or not, they will not have been spent in vain. . . . . Every shareholder, and every person in any way committed to that dreadful mistake is now in theory at least a necessary opponent of the works that are essential to the material progress of India."[1] That opinion did not agree with the North-Western Provinces Public Works Report for 1869-70, when, without the Ganges canal and other irrigation canals, there would have been a famine. It was there laid down that the irrigation canals by producing, and the railways by carrying the produce, warded off a famine from Northern India. He believed Sir Arthur Cotton overrated the advantages of canals as a means of communication. The Ganges canal, although con-

[1] *Vide* "The Madras Irrigation and Canal Company." 8vo. Madras: Graves and Co., 1860, pp. 55 and 56.

structed for and used by barges, was almost worthless as a means of transit; nor was the revenue derived from tonnage dues of any material importance.

It was stated in the Paper that 50 per cent. of the cost of the works was spent on engineering and for unused stores. That seemed to be a very large percentage indeed, and he could only attribute it to the fact, that the money expended on these works was capital guaranteed by the Government of India. He had obtained from Mr. Fleming, who conducted the affairs of the Elphinstone Reclamation Company in Bombay, an unguaranteed work, to a successful termination, a return showing the cost of engineering during the construction of those works, from which he found that when, as in 1866, the expenditure was £350,000 for the year, the engineering cost $2\frac{1}{2}$ per cent.; afterwards it was, on £280,000, 3 per cent.; on £140,000, $6\frac{1}{4}$ per cent.; on £180,000, $4\frac{3}{4}$ per cent.; and in 1870, on £100,000, it was 7 per cent. In 1868, Mr. Aitken reported that the cost of engineering many miscellaneous works in the town and island of Bombay, aggregating several hundred thousand pounds, was 4·8 per cent. on the expenditure. In the Public Works Department, which was burdened with a number of persons who were not available for strictly engineering work, the cost of engineering was understood to be 25 or 30 per cent. on the money expended. He therefore thought some explanation on this point was due; for, even allowing £500,000 to have been expended on engineering and unused stores, there was still a sum of about £250,000 unaccounted for, and available for cost of management, &c.

If there was no error in the Paper, it condemned most effectually the guarantee system when applied to canals, which ought to be treated as remunerative works. Doubtless the guarantee system, when applied to railways, had enabled a great deal of work to be done rapidly; but railways were required for political and military purposes, and could not in India, up to this time, be considered simply as remunerative works.

Mr. R. Rawlinson, C.B., said he could not tell whether the diagrams of reservoir embankments exhibited were for instruction or for warning. If for instruction, he thought they were calculated to teach a very bad lesson; if for warning he would point out a few of their mal-arrangements. Looking at the diagrams, they seemed to represent ordinary cross sections of a waterworks impounding embankment; having slopes of 3 to 1 on the inside and of about 2 to 1 on the outside. No puddle trench was shown below the surface, nor any puddle wall in the main portion of the bank.

The outside half of the embankment was of porous material—purposely, as it seemed: the inner portion he assumed was intended to be water-tight, or, at all events, to be made water-tight when protected by puddle on the surface. He cautioned young engineers against following such an example as that; for a lining of puddle laid on the surface was most troublesome, especially if it lay on a mass of earth liable to subsidence and motion such as water-works banks would have, and especially if the material on which it rested was in any degree porous. Now, although he did not in all respects agree with the modern practice of sinking a puddle trench to a great depth (150 feet in a recent case) to get to what was supposed to be a water-tight stratum, yet he held that the practice of sinking a puddle trench to a moderate depth was one which might be safely followed; and he also held that the modern practice of constructing a puddle wall in the centre of the bank had some advantages if the puddle wall was supported by carefully-selected material, that was, by a pyramidal core of water-tight material. The tail of the outer half of the bank might then be of porous material, and even the inner foot of the bank also, the core being sound and water-tight; but to him a porous bank in the way shown on the sections, either for first construction or subsequent repair, was, in his opinion, very defective engineering, and might prove to be a very misleading, because dangerous, operation. If the inner slope was of a material not in itself water-tight, there was a method to make it so far better than by putting puddle on its surface. If, when the reservoir was being filled with water, and as the water gradually rose against the bank, a number of men were placed along the water line with flat bars or grafting tools, and were instructed to run them down well into the material, and shake them so as to wash in any loam with the water as it rose, that would make the surface non-porous to the depth the operation was carried down, and such process would be less costly than puddle; the sun would not cause cracks, nor would vermin have the same facilities for getting through it as through puddle.[1] He agreed with the Author that it was better to lay broken rubble

[1] The mass of an embankment to impound and confine water under pressure should be sound and perfectly water-tight without the aid of puddle-lining, or surface washing and warping, as described, or risk of a catastrophe would be incurred. A little care in forming a reservoir embankment is of more value than a large expenditure in subsequent repairs to patch leaks, which, as a rule, cannot be patched. The three rules in reservoir works may be thus stated—care in selecting a site, in placing the material, and in filling and subsequent working.—R. R.

on the inner slope in preference to masonry pitching. He thought masonry pitching, or wall stone, or block-in-course, formed a dangerous coating for the inner face of a waterworks bank, as the stones were liable to jam and make an arch beneath which cavities might form, and the mischief go on for a time till a failure occurred without the engineer knowing it. When a puddle trench was in rock or stable material, it was sometimes the custom to cut vertical steps. He cautioned persons who had puddle trenches to construct never to make anything of the kind, because of the liability of subsidence of the bank. If a tangent line of the subsidence was drawn, and the lines then brought down at right angles, it would be seen that the tendency would be to draw the vertical line from the upright face. Much mischief had been caused through the drawing away of the puddle from the vertical face. It was therefore expedient to let the puddle trench rest upon a slope not much dissimilar to the slope of the side of the hill where the work was. Supposing the site of the reservoir was not absolutely water-tight, instead of sinking a puddle trench 150 or 160 feet he would go down, say 30 feet, and would put a thick bed of concrete at the bottom and up the outer side, and then form drains from the outer face of concrete away from the trench into a man-hole, where the water that came through could be seen; so that if there was leakage it would be known that it was leakage through the substratum in contact with the concrete, and would come to daylight at the foot of the slope, and could be sent into the gauge basins for compensation without causing mischief to the bank. The engineer must exercise his ingenuity as to when and how he would do these things. Under any circumstances the outer half of the embankment, commencing from the puddle trench, should be perfectly drained in a way that the drains should remain permanent, so that the engineer should have the opportunity of seeing any water coming from that portion of the subsoil of the bank, and if the water did not come away muddy he might rest satisfied it was not doing his bank any harm. If after-repairs to the bank were necessary in the line of the puddle-wall, he recommended engineers not to make the repairs good with puddle, supposing it was a soft bottom which caused leakage, but to use concrete.

Mr. E. A. Cowper asked how the clay was to be got into the bank? Mr. Rawlinson had suggested a means of dibbling in clay as the water rose, but he did not see how the clay was to be mixed by the grafting tool.

Mr. Rawlinson replied that clay was not necessary. Supposing there was a gravel or sand substratum to be made water-tight, loam or soil incorporated with the gravel would make a sort of concrete and would render the bank water-tight. It was not an idea which originated with himself, but was practised by early canal engineers, as on the Bridgewater canal. He had made a service reservoir, situated on sand, perfectly water-tight by the process of washing in loam with flat bars as described.

Mr. BEARDMORE said he had known several banks in which no puddle was used; for instance, the North Level sea-banks were said to be chiefly composed of sand. If there was liability to rapid lowering of the water in the Soonkêsala canal the puddle slopes would be liable to slip, and in that respect a centre puddle wall was to be preferred.

Lieut.-Col. J. G. MEDLEY, R.E., asked whether the system suggested by Mr. Rawlinson would do for running water, or did it only apply to reservoirs or still-water canals. Such puddle banks in Upper India would have to be made in some cases where there was a velocity of water of 3 or 4 miles an hour, where, as fast as the dirt was thrown down, it would be washed away.

Mr. RAWLINSON said it was self-evident that during the operation the water must be comparatively still, and there must be a sufficiency of water and no more.

Mr. R. E. FORREST said, although no one had greater respect and veneration for Sir Arthur Cotton's works on India than he had, yet he thought the views put forward with regard to canals might do great damage to the cause of irrigation. It was foolish to compare canals with railways as means of transit and carriage. Irrigation was absolutely needed; but Sir A. Cotton wanted to combine navigation with irrigation. Now it was difficult to combine the two, the requirements being so different. A navigable canal required a sluggish flow of water; but for an irrigation canal the faster the current flowed the better. A high velocity saved cost and gave a better irrigating machine. The ordinary problem that presented itself was two big rivers with a tract of land between them; and the water had to be taken from one of those rivers to irrigate that tract. The best line for carrying the canal was on the ridge between the two rivers, because it then commanded the land on each side. But this central ridge was generally the poorest and least populated, and that was the reason why an irrigation canal was wanted there. All the large cities lay along the big rivers, and to carry goods canals must be made from city to city. Therefore at starting it was found the irrigation canal ran where there was no traffic; in fact, did not go near the large markets.

The slightest change in the section of a canal of the usual size in India made such a difference in the cost as to affect the whole question of the returns. For a canal, which he projected a short time since, he was told that to enable boats to stem the current the velocity must not exceed $2\frac{1}{2}$ feet per second. Supposing the current had a velocity of $3\frac{1}{2}$ feet per second, to make it navigable it would be necessary to change the whole design, and the cost would be nearly doubled. In his opinion it was preferable to keep the two questions of irrigation and navigation entirely distinct; and as food was the first necessity for the resident population, he thought it would be better to construct irrigation canals at once, leaving the consideration of the facilities to be provided for its transport to more distant localities, whether by navigable canals or otherwise, to be dealt with hereafter.

The system of canals in India was not generally understood, but it was very simple. The canal started from a big river to irrigate a tract of land, with the water running at as high a velocity as the bed would stand. It was necessary to design the canal to carry 3,000 cubic feet of water per second in the monsoons, and only about 1,800 feet in the winter season. When in addition arrangements for navigation had to be made, it swelled the cost to such an extent as to make the returns almost problematical. He spoke from experience of some large canals which had been projected by European engineers. Without the arrangements for navigation, such as locks and still-water reaches, and as irrigation canals alone, they were calculated to give a return of 8 or 9 per cent., but when arranged for navigation it would be rather difficult to make them pay 4 per cent.

Considering that it was so difficult to get money for irrigation works, that in India there was a disinclination to raise more money by additional taxation, and that railways were better adapted for carrying than any other means of conveyance, he thought it would be better to make the irrigation canals, and to leave the navigation alone.

Mr. J. H. Latham, in reply upon the discussion, said, with regard to the face walls, Fig. 8, that there were 5-feet counterforts, 16 feet apart, from centre to centre, on the water side of the wall. Considered as a retaining wall, it was stronger than many to the west and south of London, but not so strong as would be built were the sleepers of the permanent way laid close behind the coping. The gravel was not water-worn, but quartz split into irregular crystals, and was much rougher than water-worn gravel.

The masonry revetment, Fig. 9, was not lying on clear sand, as had been supposed; it was silty river sand, and a section would stand vertically 12 feet high when dry; but water would percolate through it. The puddle at the toe ran across the whole of the canal bed, and so made it water-tight, and prevented any percolation. In the flood of August, 1870, when 12 inches of rain fell in twelve hours, the water topped the masonry revetment, and it was then not a question whether the wall was a sound one or not, for the sandy bank behind must have been washed away. The revetment wall, which was not a self-supporting wall, but rested upon the bank, of course failed; but the face-wall (Fig. 8) had never suffered.

The Soonkêsala anicut (Fig. 4) was generally upon solid gneiss, and occasionally trap; but hitherto there had been no danger from the rock being carried away. The Rajôli anicut (Fig. 6) was upon limestone, about 10 inches thick in the bed; and though limestone was a treacherous formation when beds of dirt lay between the strata of stone, in this case the stone was solid, and, as the fall was not great, it was uninjured. The Jutoor anicut (Fig. 5) was in a part of the river that contracted below the weir, and consequently, before there was much water flowing over, the crest of the weir was almost 'drowned.' The fact that the water-cushion had not suffered therefore proved little. Indeed, the spoil, or rocky deposit of the river, rose in rear of the water-cushion, and when the water ceased flowing over the weir the standing water almost concealed the crest of the lower wall of the water-cushion. Nothing with regard to water-cushions could be learnt from that. He supposed, from the fact of the face-wall (Fig. 8) not having given way under the great flood,[1] that the work was good. Great care was taken with it, and it was built under close supervision and inspection over very short lengths at a time.

As to the imaginary sections, he considered it an advantage to have puddle in front, where it could be got at, not quite on the slope, but protected in front. Care had to be taken of the quality of the puddle. If it was liable to run it could be put farther into the bank, and a greater weight of gravel and shingle laid in front to hold it up. But the puddle was not the only protection; it lay upon earth; and a sun-crack running through the puddle would not be liable to run continuously into the earth, which was not homogeneous with it. Even if leakage existed, the bank might

[1] When a portion of the old wall gave way, as Mr. Dodson described, under the flood of August, 1870, the water was suddenly lowered in the canal in front of the face-wall; but the face-wall stood that test without any cracking or failure.—J. H. L.

theoretically be constructed so as to be secure, as in Fig. 14. In practice such a delicate arrangement of stone and sand would be difficult to obtain, but with puddle in front the leakage was so small that such refined selection was not necessary. In cases of rock foundation, or of irregular foundations of different kinds of strata, the subject was too wide to enter upon. But he had shown a puddle trench, with sheet piling in the centre (Fig. 17); the object being to throw down the leakage, so that whatever there should be must flow out clear of the bank, without any tendency to scour or remove the material of the bank itself, or the material on which the rear of the bank rested.

The relative merits of railways and canals in America and India were very different. In the former case railways had been used for opening out the country; but in India canals were more suitable. In America every man understood a good deal about the repairs of railways. In almost every hamlet the first thing erected was a sawmill, and in the larger towns wooden lattice girders could be bought ready for use. In India the people knew little or nothing about railways; but they did understand irrigation. In every village there were a number of woddahs, or native navigators, and in every district a large expenditure was incurred annually in repairing tanks, wells, &c. While in America the country was opened out by railways before it was inhabited, in India the first thing was to provide some means of irrigation, if it were only by wells: but after the country had been opened out by canals, railways would be necessary for developing trade. He believed that if a tract of country were opened out by a canal it would often be found the cheapest means of commencing a traffic to make that canal navigable; and he thought that this course had been wisely pursued in the canal under discussion. It had a series of up-takes from different rivers; and consequently never got so far from the large towns, which were generally near the river side, as the Ganges canal. It was the reverse in another point: the Ganges main canal had a fall of about 18 inches a mile, and the distributing channels less fall; and thus, when the distributing channels were full, there was a current of 3 miles an hour: whereas in the Soonkêsala canal the usual fall was 6 inches and under; that of the channels was 2, 4, or 6 feet a mile; and there was scarcely a mile and a half in any portion where the current at all approached the velocity of 3 miles an hour. In the Soonkêsala canal the chief supply of water for irrigation was taken off from the canal just above the first drop-lock in each branch; so that if irrigation were in full action, the navigation down to the locks, and of course in the ponds between the locks, must be complete. This was not the case in the Ganges canal. The banks of the canal almost necessarily ran across some rather deep hollows. An investigation was made of the relative cost, and additional length, of running round some of the valleys instead of across them, and the balance was struck. In one case, where the circuit of the valley was made, 1 mile was thereby lengthened into 3 miles. In other cases the ratio of increase would be greater, so that it was best to carry the canal across these valleys. There were no masonry falls in the canal, and the scouring action of the under sluices in the weirs was local. In more recent works the head sluice was at right angles to, and close upon, the under sluice, the latter being 3 feet lower, so that the scour took place across the whole face of the head sluice. The sand in the Soonkêsala anicut for almost the whole length lay within about 18 inches of the crest.

No attempt had been made to deliver water by measurement; and though he had taken 2 cubic yards per hour from the Madras Government as the datum on which to calculate the capacity of irrigation, he had no more faith in that than he had in the previous Madras practice as regarded provision for drainage, which turned out fallacious. There had been no experiments to indicate how much water per hour per acre was required in that part of India. In the consideration of works of irrigation in Jamaica in 1871, the Surveyor-General of Jamaica, after careful inquiry, adopted 1 cubic yard of water per hour for rice irrigation; he imagined that was enough for a rice crop, and that 2 cubic yards an hour would be too much.

The cost of the engineering staff on these works included that of the surveys for the Nellore part of the works, the Bellary scheme, and the reservoirs; also stores sufficient for executing the whole of these works; so that it was an exceptionally large percentage. But there were no contractors; the engineers themselves did the work which was usually done by contractors; and he did not think engineers would be content to carry out works of this kind at 4 or 5 per cent., including the cost of all the subordinate staff, and of both Home and Indian establishments.