THE TRAINING WORKS ON THE SUTLEJ AT RUPAR.

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Historical—

The Sutlej rises in the Himalayas beyond the limits of civilization. At Bhakra, some forty miles above Rupar, the river breaks through the outermost range of the Himalayas, in a narrow gorge, and from Bhakra to Bharatgarh, runs in a single bed, with rapids, through a wide valley between the Himalayas and the Sawaliks. From Bharatgarh to Rupar, the river flows through the Sawaliks, and the shingle is lost sight of, although it still exists at increasing depths. At Rupar, the river breaks out on to the alluvium of the plains and wanders about in ever-changing channels.

It was the high hills on the right bank, and the low hills on the left, constraining the river into a fixed channel, that led to the location of the headworks of the Sirhind Canal at Rupar.

Mr. Beresford estimated the catchment area above Rupar to be 7,200 square miles, the length of the basin 150 miles, and the maximum discharge 3,50,000 cusecs, or 49 cusecs per square mile.

A reduced scale plan of the original survey of the river, made in 1874 for the location of the headworks, shows the state of the Sutlej at the commencement of the construction of the canal. The river comes down along its right bank in a curve at the foot of the hills, where it cannot erode, to just above Garhbaga. It is therefore fixed at this point, and at the construction of the canal it was assumed that no training works would ever be required. The villages of Alampore and Kutli had existed for generations on the high land of the left bank, indicating that the river was also stable on this bank.

At the site of the weir, the main channel crossed from the right flank to the site of the undersluices ; this was a favourable condition, and in order to maintain it the axis of the weir was shifted fifteen degrees upstream, and a [illegible] slope of inches given towards the sluices.

The weir was built with its crest five feet above normal winter water surface. This height was fixed by the fact that the full winter discharge could be drawn into the canal, with the water surface upstream of the regulator level with the crest of a weir of this height.

The canal was opened in 1883, and the survey of 1885 shows how the river had changed since construction was started. The whole stream hugged the left bank and went straight for the undersluices, but this condition was still satisfactory.

In the year 1886 trouble from silt first occurred in the canal, and the weir crest was raised 1·5 [illegible] and made level. Shutters were also added, first of all 2 [illegible] feet high, but later this was increased to 6 feet. Thus the pond level above the weir was increased 7½ feet above what was the normal high water level of the hot season, and 12½ feet above the normal water level of the cold season ; and to what extent the training work that has since become necessary is due to the changes in level referred to above, is an interesting matter for consideration.

The following figures give the reduced levels at the weir, and at Patial gauge four miles upstream of the standard gauge below the weir, or 17,000 feet above the weir, for as nearly as can be estimated equal discharges :—

	Patial, 4th mile.	Weir.	Slope.
1870	.. 868·9	... 861·7	... 1 in 2[illegible]
1913	... 873·6	... 871·5	... 1 in [illegible]0
1913	... 873·6	... 863·1	... 1 in [illegible]630

The last line gives the figures during a closure with the sluices all open.

In the hot weather the gauge above the weir is maintained approximately constant when the canal is open by dropping shutters, but the gauge at Patial rises with each increase in the discharge so that the slope again changes.

	Patial, 4th mile.	Weir.	Slope.
1914 snow river	877·6	... 871·0	... 1 in 2600
1914 medium flood	879·0	... 869·2	... 1 in 1730
1913 third highest	882·7	... 875·2	... 1 in 2270

It would therefore appear that when the natural slope of a ver, originally 1 in 2360, is artificially raised from 1 in 8000 1 in 1630, instability of the channel is bound to occur. n the basis of present accepted theories, when the slope is ore than the original natural slope, a river would tend to engthen its channel, and the necessity for training works may possibly therefore be attributable to this cause alone.

Taking the river as shown in the 1874 survey, the changes that took place may be outlined as follows :—

In 1882 the main channel had left the right bank where it was running in 1874, and all the water passed round the curve of the left bank. The right channel then only took a small portion of the high river and silted up to a great extent.

The end of the island above the weir was eroded, owing the bulk of the water coming down the left channel spread- ut after passing Kutli on each side of a shoal of shingle, had formed. In 1882 the lock channel bund was ucted, and the bank above Kutli was lightly pitched to nt erosion, as the river had concentrated on the left bank e Kutli before it struck over to the right flank of the weir. Spurs were added upstream of the right flank of the weir to prevent erosion and any falling in of the vertical face of the hill, which is 200 feet high.

In 1887 the left bank having begun to erode, three spurs were put in as noted on the survey plan of 1885. It was further proposed to open out the right channel by excavation, and land was acquired for this purpose, but the proposal was not carried out, as the river did not continue to cause damage.

In 1890 erosion took place between the spurs upstream o Kutli, and a spur was added below the village to prevent the lock channel bund being out-flanked.

By 1892 the channel from Kutli to the right flank of the weir had become much obscured, and the greater portion of the water passed direct to the sluices. The right bank channel continued to carry a small discharge.

In 1893 the spur at Alampore was washed away. This was the year of greatest anxiety on the canal, owing to silt trouble, and the divide wall was built and the regulator remodell Mr. Farrant pointed out the necessity of holding on to the le bank from Patial to Kutli, and submitted an estimate for abo Rs. 50,000 to protect it efficiently When submitting estimate, he laid stress on the fact that the river was bound to continue to eat out the left bank unless it was protected, and, at the same time, stated that the protection of the bank, which at that time would cost Rs. 50,000, would cost five lacs when the bank had once gone. Time has since shown how near this was to the truth. In 1894 the whole left bank with the spurs from Bahadurpore Choa to Kutli spur was eroded, and Alampore village vanished into the river.

Before the flood season of 1895, it was decided to limit all upstream training works to Kutli spur, which was strengthened, and to allow the river to do what it liked above this point. During this year's flood, the small spur below Kutli was wiped out, and the river attacked the lock channel bund. In 1896 further embayment took place above Khwaspur Choa, and threatened to out-flank Kutli spur, so that a new spur had to be built, which is shown at the root of new Spur No. 3, on the survey plan of 1914. Kutli spur was also strengthened. The out-flanking caused the main channel to cross from behind Spur No. 3 to the right flank of the weir, with a subsidiary channel which eroded the bank between Kutli and the lock channel.

In 1897 Spurs Nos. 1 and 2 were built to develop a straight channel to the sluices from Kutli spur, and prevent any further erosion such as had started in 1895 below Kutli.

By 1899 the shoals above the divide wall had decreased, owing to the construction of Spurs Nos. 1 and 2, giving a good straight channel to the sluices.

In 1901, owing to erosion continuing above Spur No. 3, Spur No. 4 was built.

In 1904 owing to continued erosion further protection was required above Spur No 4, and the nose of Alampore Choa was pitched together with the whole curve down to Spur No. 3

1907. Since the embayment started, the river ran in two channels between the island and Alampore, but from this year the river hugged the left bank in one channel, and, coming from the embayment at Spur No. 3, shot across to the island, and shoals commenced to form near Spurs Nos. 1 and 2.

1913. The embayment still continued, Spurs Nos. 1 and 2 were entirely out of action, and the regulator was masked by shoals covered with bulrushes which could not be moved by ɔsures for scouring, as the water only dug itself down into a ɦannel along the island, and then across at right angles to the ɔse of the divide wall.

The question of constructing training works, to restore the ver to its original curve, above the existing training works, was y this time being seriously considered, but, as there was not ufficient time to carry out any large work prior to the monsoon, ι temporary spur of concrete blocks was built above Alampore, ιt a cost of Rs. 18,000, which fulfilled its purpose of preventing urther embayment, and the outflanking of the existing works. A two-foot gauge tramway line was also laid from the headworks ιll along the river bank, with bridges over the torrents, so as to ɜnable materials to be readily moved, as the reserve of pitching ;tone was only one and-a-half lacs. All training works in the ɒast had been constructed of boulders boated down the river, ιut that source of supply had been worked out. New tramway lant was accordingly obtained, and a line laid to Nalagarh, the Himalayas, fourteen miles from Rupar, which had been he source of supply for stone during the construction of the anal, and was the nearest point where stone was available.

Alignment and design of new training works.

After the usual number of alternative proposals it was lecided—

(*a*) To align the heads of the new groynes on a curve joining the straight length of the original river bank at Patial, which had not been eroded, and the line of Spurs Nos. 1 and 2 ; the curve was to be tangential to both these lines, starting from the centre of Spur No. 2. This curve, as nearly as possible, re-produced the original river bank prior to embayment.

(*b*) The heads of the groynes were to be of the type built below the weir at Khanki, a drawing of which was supplied.

(*c*) The groynes were to be spaced 2,500 feet apart, as previously adopted at Rupar and at Khanki. This brought Spur No. 6 just at the end of the straight below Patial, where no erosion had ever occurred, and it was considered desirable to hold on to that point.

(*d*) The tops of the groynes, and the top level of the shanks, were to be five feet above the line of maximum flood obtained from the readings of the gauges at Patial and above the weir.

(*e*) Construction was to be carried out in the dry, after diverting the river into the right bank channel.

The construction of the works will now be outlined and an account given of how they acted in the first flood season.

Supply of stone.

The laying of the line to Nalagarh—a distance of $12\frac{1}{2}$ miles from Alampore—could not be started until after the monsoon was over, as it was to be laid as a surface line over torrents, the largest of which was the Sirsa some two miles wide. Laying was started on 1st October, and the first train of stone reached the work on 30th November.

There is a length of $1\frac{1}{2}$ miles at a grade of 1 in 66 to the quarry, up which a thirty horse power locomotive can haul thirty empty trucks. Against the returning full train the worst grade is 1 in 120 for half a mile, and here the engine can haul the same number of loaded trucks. For carriage of stone the ordinary wheels and frames of Hudson 27 cubic feet trucks were used, with a timber tub of 33 cubic feet capacity made locally, instead of the ordinary tipping tub, as it increased the capacity and gave steadier running. One engine and train could make three return trips to the quarry a day, running a distance of eighty-four miles.

A two foot gauge line for the supply of stone, over a long distance with heavy grades, thus shewed itself to be feasible. The cost of laying the line, including earthwork and bridges, (eight spans of 20 feet and twelve of from 5 to 8 feet) was Rs. 18,000, which with other standing charges amounted to Rs. 27,000, and this amount was distributed over an outturn of twelve lacs of stone. The estimated rate of stone measured in stacks at Rupar, was Rs. 13-12-0, but it actually worked out to be Rs.13-4-0 including Re. 0-12-0 royalty.

Diversion of river.

Whilst waiting for the river to fall, it was decided to divert the channel, and two temporary spurs were constructed to prevent erosion of the diversion bunds, as shown on the survey plans of 1914. These spurs, with aprons, twenty feet wide and two feet thick, (a portion being crated) were founded on a substratum of sand and shingle, and withstood the action of a flood which occurred in May before the diversion bund had been cut. These spurs were also connected the nose of the island by a bund, to close all connection between the two branches of the river.

The closing of the left branch was effected as follows:— earth was boated out and a small bund made on the shoal, the ends being protected with gunny-bags, while, as it would be much easier to close a wide shallow opening, than a narrow deep one, mattresses of wire-netting, four feet wide, four inch mesh, 14 B. W. G. covered with pilchy, were made of suitable sizes for the depth of the water and the position; and the whole of the bed was then mattressed with the object of preventing scour anywhere, owing to the constriction of the water-way, and increased velocity.

The left bank channel was first taken in hand, and concrete block abutments were built on fifty foot mattresses to carry girders twenty feet in span for the tram line to take out earth. This bridge was a great assistance in relieving the heading up up-stream. The closing of the width of shallow water beyond was done on an eight foot wide mattress, though this may seem to have been unnecessary. Soundings were taken upstream and downstream every morning and evening to see the depth of scour beyond the mattresses, as had this become excessive, and the mattresses once broken anywhere, the whole work would have gone for nothing, as the river would have rapidly deepened. The lowest scour levels have been plotted on a diagram, and in every case it will be seen how much the bed scoured up and down stream.

Before closing the left channel, a bund, with its head pitched with gunny-bags, was run out at right angles on the shoal, to prevent facial flow upstream and consequent trouble. The abutments on the shoal of the right channel had also been strengthened.

The arrangements for the final closure were then put in hand. It was calculated that the 4,000 cusec which were passing could be constrained to pass through a waterway 160 feet wide without a dangerous velocity. The island abutment was completed with concrete blocks $4' \times 4' \times 2'$ backed by gunny-bags, to withstand the final four to six feet difference of head expected, and the abutment 160 feet away was built of concrete blocks. Intermediate piers were also built at twenty foot centres.

By the evening of the 5th December the whole width from the gunny-bag abutment, up to the 160 feet space to be left, had been closed. During the 6th this was made good with earth, and on the 7th morning it was decided to start the final closing of the 160 feet width, although one pier was incomplete, and the girders had not been laid across two of the spans. Loose stone was first thrown uniformly in all spans until it began to roll out of position. It was then filled in crates 8′ × 4′ and 4′ × 4′, of the wire netting on which the mattresses were made. These crates were filled on the piers and tippled off, and also on sleepers projecting over the sides of boats. None of these crates got shifted, as they spread out and offered a maximum horizontal area, and a minimum vertical so that the water could not roll them away.

Having got somes crates down in the bay by the island, sleepers were put in as needles against the girders to complete the closing of this bay, and gunny-bags laid on their upstream face. This acted very well. The next two bays were brought up level with the water surface with loose and crated stone, while the last three were brought up to the water surface with stone and concrete blocks. All the bays were closed together the same amount to maintain a uniform distribution of velocity. It may be mentioned that concrete blocks 4′ × 4′ × 2′ were easily handled by the two Rupar steel crane boats especially built for such works. When the stone was showing above the surface all along the line, sheets of tarred gunny-bag were laid on the upstream slope, and well out into the river bed, to prevent the earth thrown in being washed away through the stone. The tram line was then run through from bank to bank and the earthen bund rapidly completed. The final difference of water surface upstream and downstream of the bund was 5·7 feet.

The closing of the last 160 feet started on 7th morning and was complete by noon on 9th.

The materials used in the whole diversion were fifteen lacs cubic feet of earth, 39,000 cubic feet of stone, 130 concrete blocks, 20,500 gunny-bags and 28,160 square feet of mattress; and 29,300 cubic feet of stone for the two temporary spurs. The total cost of the diversion was Rs. 29,686 while the total estimate for the whole four groynes and river diversion was Rs. 2,48,724, and in making the groynes 7½ lacs cubic feet of stone pitching, 4½ lacs cubic feet of stone ballast and shingle, and 48 lacs cubic feet of earthwork were used.

Construction of groynes.

With the river diverted on 9th December, and the bed more or less dry, the construction of the groynes presented no great difficulty. The earthwork lead was long, but a Pathan's delight. The tram line was ramped down om Alampore into the river bed, and stone trained direct into e heads.

The spur heads were all situated on shoals, on the island le of what had been the main channel of the river, so that e old river channel was entirely closed off in three places by e shanks. A covering of good clayey earth was trammed out om the high river bank, and laid on the shanks and on the heads nder the pitching. The slopes of the shanks, which were 3 to upstream and 2 to 1 downstream, were then shingled, to revent damage by wave action. The whole work was com-leted and the plant out of the river bed by 8th May, when the iversion bund was cut, and the river allowed to go back into ts original channel. The shanks of Spur No. 3 having been uilt across a hole about thirty feet deep, slid and spread, but rtunately did not let water over it. It would have been better have made both slopes of the shanks 3 to 1, as although the to 1 slope was shingled it slipped, and cost more to repair an it would have cost to have made it in the first instances to 1. The river at once took up its course in the old annel, along the shank, and round the head of each spur, spite of a channel being excavated for it in line with the ads of the spurs. When however the space between the urs had silted up, and the river rose, the channel straightened self out to the curve of the spur heads with the embayments newn on the plan.

Before letting the river back into the left channel, a tempo-ary spur was built from the island opposite Spur No. 1, to lose off the deep channel by the island, and force the water ver the malignant shoals above and below this spur. The nd was pitched with gunny-bags, and when erosion started ound its head, four boat loads of stone were thrown in to trengthen the foot of the head. This spur held for all the snow vater river and floods, until it was over-topped by the flood of 25th June. It had however achieved its object of forcing the vater to scour away the shoals as desired.

The whole of the area between the new spurs was so well ilted up that a fine crop of rice was grown, and it is estimated hat on a similar rent to that obtained for the land reclaimed y Spurs Nos. 1 and 2 in 1897, a revenue from Rs. 5,000 o 8,000 will be obtained from this reclamation which, capitalized, s a large proportion of the cost of the construction of the spurs.

Effect of Spurs on river.

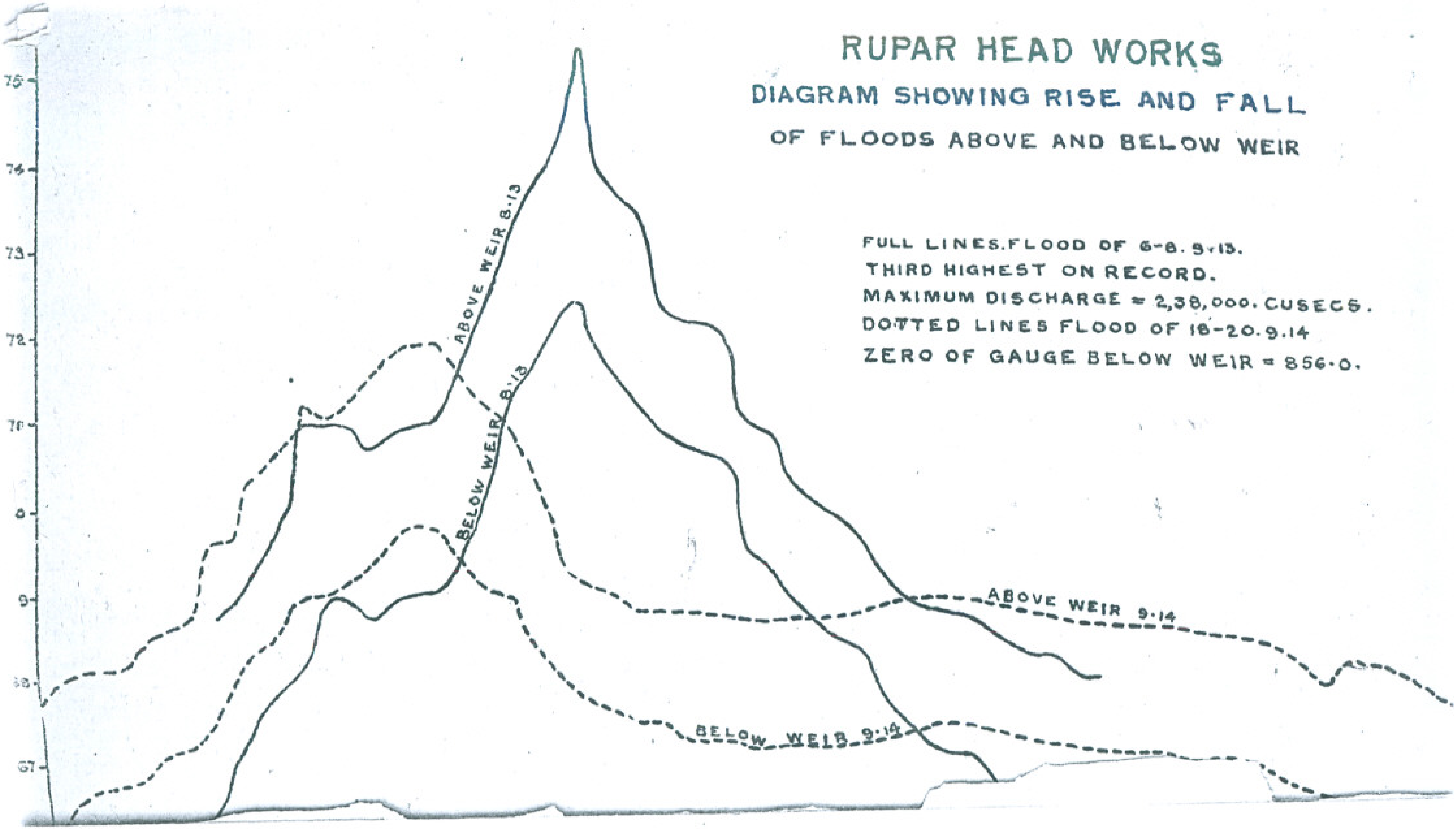
The effect of the spurs on the river has been satisfactory, the only difficulty being that coming down the straight, the hi river ran in between Spurs Nos. 3 and 4, and coming (from behind Spur No. 3, shot across into its old channel the island, instead of passing Spur No. 3 on the curve, a carrying past Spurs Nos. 1 and 2 direct to the sluices.

The river in scouring out a new channel past the heads Spurs Nos. 3, 4 and 5 in a bed containing shingle has depos ed a large quantity of the shingle in the slack water opposi Spurs Nos. 1 and 2. The removal of this shoal by scouring and compelling the river to flow in fair force past Spurs Nos. 1 and 2, is the object to be attained, as otherwise scouring by the sluices will be ineffectual. A large area of the top of the island has been washed away, and the right channel opened out considerably, the last flood in September however silted it up again to a great extent, so that the winter supply in it is small.

The continual regulation from the right flank of the weir, only induces a tendency for the right channel to open out, as from Patial to the right flank of the weir the right channel is a much shorter route than the left channel past the nose of the island, and speculation as to the future developments of the river is not without interest.

Action of the river on the Groynes.

Groyne No. 6 has not been in action at all. Groyne No. 5 was not in action in the flood season, and is undamaged. Groyne No. 4 was attacked in the latter part of the flood season and almost the whole of the seventy-five feet of apron on the up stream nose settled ; the action was however less severe than o. Groyne No. 3, where it was acute. A plan has been prepared showing the probings made to stone and shingle after the flood season was over. This is contoured and is a unique record of the action set up at the nose of a spur. The substratum of shingle that exists was considered when the spurs of 1887 were built, but since then no account has been taken of it. It may, however, have had a very important bearing on the action on the heads of the spurs. In a flood a difference of water level of $2\frac{1}{2}$ feet has been measured between X and Y (*vide* plate) and the top of the apron at the nose, on the river side, has practically become the cistern of a fall. The bed being of shingle is unyielding, so that the water-way round the nose could not increase by scouring, as it would have done in sand hence the heading up to give the increased velocity. Having got past the nose of the



RUPAR HEAD WORKS
DIAGRAM SHOWING RISE AND FALL
OF FLOODS ABOVE AND BELOW WEIR
FULL LINES. FLOOD OF 6-8.9.13.
THIRD HIGHEST ON RECORD.
MAXIMUM DISCHARGE = 2,38,000. CUSECS.
DOTTED LINES FLOOD OF 18-20.9.14
ZERO OF GAUGE BELOW WEIR = 856·0.
ABOVE WEIR 8.13
BELOW WEIR 8.13
ABOVE WEIR 9.14
BELOW WEIR 9.14
75
74
73
72
67

groyne head a seve /swirl action was set up, which dug out the hole shown by the contours. During the flood season the surging action of the $2\frac{1}{2}$ foot fall round the nose sucked out the sand from under the apron and side slope, which settled and fell in, but fortunately reserve stone was thrown in and the nose was held.

The probings round Spur No. 1, where there is no difference of water level on the two sides of the nose showed that there was only a scouring action, and the apron was not pounded out of place by any fall action. It will be noticed in all the spurs that the action has only taken place on the upstream nose ; and that the rest of the apron has been practically undamaged.

On rivers near the hills with training works, the time factor is very important in floods, as they come rapidly and vary the conditions greatly, but last only a short time. A diagram is attached showing the hourly rise and fall of the third largest flood on record and also of a normal high and long prolonged flood.

Discussion.

Mr. Nicholson, in introducing the paper, said he had endeavoured to keep within the five thousand word limit allowed for a paper, but actually he had been well below the mark. He had drawn up his paper from an historical point of view, giving details of the development of the training works, and he had refrained from discussing the merits of the procedure adopted from time to time, as that would have materially lengthened the paper ; he, however, hoped that, in the discussion that would follow, members would raise any points that they considered needed elucidation, and that some railway men would give their views on the method adopted. The details regarding the diversion of the river for the new training works were given, because so far as the author knew, no one had left on record details regarding the procedure adopted in making a diversion, although it had frequently been done during the construction of canal headworks.

The Sirhind Canal had been opened in 1883, and the survey of 1885 shewed how the river had changed its course since 1874. In 1886 silt trouble commenced, and reached its maximum in 1893, when the regulator was remodelled, and the divide wall put in to form the pocket.

In 1912 persistent shoals overgrown with bulrushes on which closures for scouring had no effect, existed upstream of the regulator as far as Spur No. 1, while the river had embayed so much above Spur No. 3 that it shot across to the island and thence to the fourth bay of the weir. The river being thus out of control, and scouring being ineffectual, it was deemed desirable to construct the training works described.

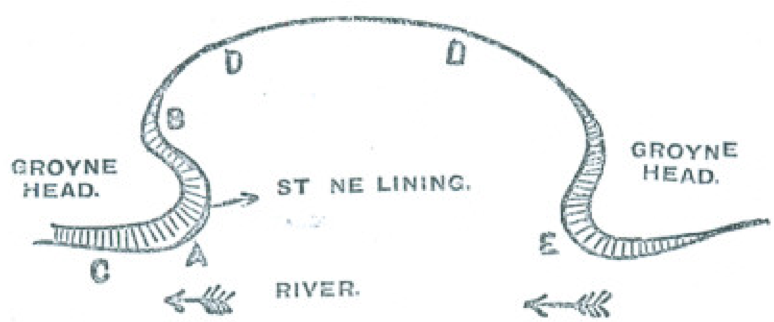
The effect of these training works had only been seen for one year, and it would be interesting if any members would give their opinion on what the future conditions in the river would be as a result of the construction of these spurs. Statements now made would be of much more weight than any made a few years hence to the effect that " any one could have been able to foretell such a result."

Mr. Harvey felt it would be very instructive if the author would give reasons why the training of this river was continued on the now out-of-date method of " spurs," instead of by the Bell bund method. They all knew the Bell bund method, which essentially consist of two training bunds along the length of the river, each with an impregnable head and two approaches more or less at right angles to the direction of flow. These approaches might be the railway bank or marginal bunds or some other form of embankment. From the paper it appeared that constant expense was being incurred in attempting to keep the river in the right path (apparently with rather less than more success) by means of spurs.

RAI BAHADUR BISHAMBAR NATH said he had nothing to say in regard to the works at Rupar, but wished to say something about Bell's bunds. Though the principle of these bunds was established, and it would be presumptuous on his part to say anything against them, still he would like to state what his experience of them had been, and he would be only too pleased to be shown any mistake in the opinion he had formed in regard to them. While admitting the usefulness of Bell's bunds against ordinary erosion, he found they were of no use when the set of the river was directed against one particular point, as had been the case at the Chenab railway bridge near Sher Shah, where a Bell's bund had for the first time been constructed. Rai Sahib Sheo Nath of the North Western Railway was in charge of this work, and the speaker used to go out with him and watch the action of the river on the bund. At one particular point, as far as he could remember, it was the extreme point upstream, where a groyne had been made on Bell's principle, the river attacked the bund till the groyne gave way, and, in order to hold that point and save the bund from being outflanked, many train loads of stones had to be deposited. The stone thus put in amounted to such a large quantity that the original quantity placed on Bell's principle formed only an insignificant fraction of the whole, and he would like to know where was the usefulness of the Bell's bund in that particular instance, and where was the automatic action that was expected of it for lining the bank as the erosion of bed and bank proceeded when attacked by the river.

His own way of making a groyne in a similar position, at Dera Ghazi Khan, by means of which he had successfully repulsed the fiercest attacks of the river for some four or five years, till he was transferred from that station, had been, before the commencement of the flood season, to line the slope of the earthen groyne head all round with large bags of stones in munj nets or *trangar* rolled down into the water, one after the other, till the lining was several feet above the cold weather level. When the river was in flood and erosion of the bed started, the lining bega slide down, and, in order to keep it well above flood level at l times, more *trangars* of stones had to be piled on top. This ent on throughout the flood season till the lining reached the west point of the bed eroded by the river during the season. ı this way, the lining took two or three years to reach down to ıe maximum limit of bed erosion. This method, however, emanded constant watching of the stone lining, and sometimes ecessitated gangs of Pathan coolies at night for keeping it well bove the flood level.

The attached sketch illustrates the position on the right ank of the Indus at Dera Ghazi Khan.



The maximum depth of water at A was fifty-five feet when only waist deep at D. D. The point 'A' gave no trouble, but the points B and C suffered severely from back water, and required constant attention during the first flood season, the river trying, as it were, to cut through the neck B C.

If such groynes were constructed at suitable distances apart along the bank of a river, there would be no necessity for pitching the intermediate lengths with stone, as these could at most only be cut away as sketched, the river could not do any further damage so long as the heads A and E were held fast.

This method of constructing groynes resulted eventually in economy in stone and the certainty of having a continuous lining from the greatest depth of erosion in the river bed to well above high flood level.

This, however, did not seem practicable in a Bell's bund, where there might be only four feet of stone over a depth of twenty feet of earthen bank, in which case with one cubic foot of stone there would fall into the river five cubic feet of earth, resulting in the stone being widely separated, and the formation of a *continuous* stone lining prevented.

MR. SCHÖNEMANN said Mr. Nicholson had given them a very interesting and satisfactory description of the construction of the Rupar works, but his explanation of the necessity for these works left a void in their satisfaction. Why had they gone in for training works ? Was it for purposes of land reclamation ? Or was it in order to benefit the canal *qua* silt regimé ? Or was it for the protection of property.

The author had given them a map showing what the river was like in 1874, and the idea in 1914 appeared to have been to give the river the same shape as in 1874, but why had this particular shape of 1874 been thought so desirable ?

The survey plan of 1874 shows that the river at that time hugged the left bank from Patial to Alampur, and then made an abrupt right-angled turn to the right, across its own axis, till it struck the right bank at right angles ; whence it proceeded for a short distance along this bank, and then struck across diagonally to the point on the left bank where the undersluices now are. From this plan it seemed that the course of the river near Alampur in 1874 was neither normal nor stable, that its declivity was excessive, that the Alampur bluff was liable to be scoured away even if the Rupar weir had not been built, and that the erosion of this bluff in 1893 was not proved to have been the result of the construction of the weir.

Mr. Nicholson had stated that in 1874, at the site of the weir, the main stream of the river crossed from the right flank to the site of the undersluices, and "that this was a favourable condition." He had also stated that in 1885 the whole stream hugged the left bank and went straight for the undersluices, and that this condition was " still satisfactory." If, however, it was satisfactory and desirable that the main stream of the river should impinge directly on the undersluices, it was difficult to understand the object of the series of spurs that had been built out from the left bank in 1914, of which the effect would be to divert the main stream from the left bank towards the right flank of the weir ? It was also difficult to reconcile the Rupar practice of the past twenty years, of keeping the main stream on the right flank of the weir, as far as possible from the undersluices, with Mr. Nicholson's view that the main stream ought to go straight for the undersluices.

Mr. Nicholson had given figures to show that in 1870, the declivity of the water surface of the river, from Patial to the weir, averaged 1 in 2,360 ; and that, in 1913, for approximately

e same discharge, the declivity was 1 in 8,100, with the weir
›sed and canal open, and 1 in 1,630 with the weir open and
e canal closed. It was difficult, however, to understand why
e declivity of the river from Patial to Rupar should be so
uch greater after the construction of the weir, than before that
ent, since the weir offered a considerable obstruction to the
/er's flow, and some degree of afflux. Mr. Nicholson's idea
emed to involve the assumption that, if the weir had never
en built, the declivity of the stream from Patial to Rupar
ould have remained always about 1 in 2,360; and that it
ould never, of its own accord, have increased, even temporally,
1 in 1,630, but with this he could not agree. In his report
the Jhelum Canal project of 1887, Major Ottley stated that
e water surface slope of the Jhelum river at Rasul, as carefully
rveyed on two occasions by Mr. Atkinson, was found to be 1
4,650, and 1 in 3,765, respectively, whilst Mr. Brodie, from
parate surveys, arrived at values of 1 in 6,250, 1 in 8,125,
d 1 in 13,050, respectively, for the same datum. All these
lues for the water slope of the river Jhelum were recorded
ng before the construction of the Rasul weir was commenced,
d they showed that the water slope of a river was not the
ed and immutable feature of its physique that the author
pposed. Mr. Nicholson had stated that, when the slope of a
/er exceeded its original normal value (whatever that might
!), the river tended to lengthen its channel, and this necessitated
aining works, but, if the steepening of the declivity of the Sutlej
Rupar on some occasion from 1 in 2,360 to 1 in 1,630, tended
make the river lengthen its course, surely the flattening
the declivity at other times to 1 in 8,000 ought to have
e opposite effect. The declivity of 1 in 1,630 was presumably
›tained at a time when the river was not in flood, otherwise
did not see how the weir could fail to cause an afflux with
upstream flattening of the surface slope. Erosion, on the
her hand, such as might necessitate training works upstream
the weir, would occur presumably only under the influence
high floods. If the construction of the weir had led to
osion miles upstream, as suggested by Mr. Nicholson, the
aining works of 1914 would probably cause something of
e same sort, since they were, after all, partial weirs, and Mr.
icholson had mentioned that, during a flood, a water fall
$2\frac{1}{2}$ feet had been observed at the nose of Groyne No. 3.

The worst feature of river training works at the head of a
nal, was the temptation they offered for never-ending expendi-

ture. It was a fascinating employment to the local engineers to experiment with groynes and bunds ; and to speculate on a subject which admitted neither of conclusive proof nor of unanswerable contradiction. The only thing certain about it was its costliness.

RAI BAHADUR BAIJ NATH said that his remarks had been, to a certain extent, forestalled by Mr. Schönemann, since he had also intended to ask why such expensive training works, spurs, and groynes had been undertaken, and why they had been found necessary. He had been in charge of Rupar headworks as executive engineer for the six years ending December 1911, and he did not understand what sudden changes necessitated such expensive protective measures.

The past history of the action of the Sutlej at Rupar, as briefly sketched by the author, clearly showed that the tendency to erosion and severe action on the left bank above Kutli and Alampur had always been great. It is shown to have existed in 1882, and in the early nineties the action above Spurs Nos. 3 and 4 was great, while the same action continued in 1904.

Mr. Nicholson described the main left bank stream as flowing in one channel in 1907 as though it had formerly flowed in two, but this was not described, nor was the history of the years 1908 to 1912 given, though this would be interesting in view of the fact that, as the speaker could say from personal knowledge, no great changes in the action of the river appeared to have taken place after 1907. The Alampur bank continued to be attacked, but nothing serious occurred, and the riv survey plan of 1912 on which the proposals for the new trainii works appeared to have been based, did not show any marke difference from the plans of 1909 and 1910, which, however, were not given.

The question of providing some protection to the left bank above the Alampur Choa, by spurs or by a guide bank, was considered several times, but it was stated by high authority that the sphere of training works did not extend beyond the Alampur bend, and the need for heavy expenditure on new and extensive training works was not considered as established. It was authoritatively stated that the river bend had reached the limit of its action, and could not help going back to its main channel past Spurs Nos. 1 and 2. From a comparison of the river survey plans of several years, say, 1907 to 1912, it would appear that the approach to the undersluices was improving. He remembered the severe action there used to be at the upstream noses of the T heads of Spurs Nos. 1 and 2 during 1906 and 1907, but that seems to have disappeared in subsequent years. As, therefore, in 1912 the river approach conditions were decidedly better, the need for the training works described in the paper was not clear. He invited attention to the statements made on pages 174-175 in the description of the river action for the years 1907 and 1913, and again to page 180 about the effect of spurs. This is stated to have been satisfactory, but the result was practically the same as in the years 1907 and 1913. The author has stated that, before the new training works were built in 1907, shoals had formed opposite to Spurs Nos. 1 and 2, and he mentions that in 1913 jungle and bulrushes were growing on these shoals while the new groynes are said * to have resulted in the deposit of a large quantity of shingle opposite these spurs—a state of affairs the groynes had been introduced to remedy.

Again, as to the action of the river on the new groynes, the author himself has clearly described it. No. 6 did not work at all; No. 5 did not work in the flood season; No. 4 was attacked and its whole seventy feet of apron settled; action was severe and acute on Groyne No. 3, which was the very point of attack of the river before the construction of the new groynes; consequently what use were these costly groynes? The reasons for building them were not clear, while the initial cost had been great, and would result in enormous annual expenditure in maintenance and upkeep, which for some years might be as much as Rs. 40,000 to Rs. 50,000 a year.

MR. GIBB considered that the irrigation policy in river training was a negative one, and consisted chiefly in preventing rivers from doing what they were doing or showing a tendency to do. There appeared to be no clear conception of how they were required to flow at headworks. Their river training works, of which the spurs described were an example, were designed to prevent the river doing something not wanted, rather than to make it do something which was wanted, and he thought that there was real and urgent need for a positive policy, even if it were only a broad generalisation: and, in order to stimulate thought on the subject, he would indicate briefly what he thought the policy should be.

The conditions were, a very variable discharge of water, often very heavily charged with sandy silt, flowing in an ill-defined

* Page 180.

and unstable channel or group of channels, while the requirements were to have an adequate supply of water always passing in front of the permanent canal head, from which to draw the canal supply, the water taken into the canal being as free from silt as possible.

The way in which water flowed in a curved channel, and the silt distribution under this condition of flow, suggested a possible solution of the problem. In flow round a bend, cross currents were set up along the bottom from the outer to the inner circumference, returning near the surface to the outer circumference. Silt was thus carried to the inner circumference and tended to be deposited there, while the outer circumference was continually being fed with and eroded by clear surface water. If the outer circumference of a bend were clothed with stone so as to prevent excavation of fresh material, the water there would be almost free of silt, which would all be carried across to the inside of the bend. An opportunity would thus be provided for getting clear water into the canal. The momentum of flow always tended to direct the stream to the outer circumference, provided the curvature was not too flat; so that the required supply of water would always be available on this side for a canal, and the river would only require to be confined on the outside of the bend. Floods could obtain as great an increase of water-way on the other side as was required. Thus the variable discharge of the river would be met by allowing free expansion on the side remote from the fixed canal head.

According to these principles, the object at a canal headworks would be to train the river by works only on the canal side, so as to cause it to flow in a curved channel, convex towards the canal head, and having the outer circumference clothed with stone. The bend in the Sutlej at Rupar, where the spurs described in the paper were situated, ended about two miles upstream of the canal head, after which the channel was straight, so that the bend was too far upstream to affect the flow, or distribution of silt, past the canal head; and the flow in this two-mile reach of straight channel was extremely unstable and uncontrolled. It was not clear that the spurs at the bend had anything to do with the headworks.

MR. WADLEY said he thought that a channel of control, formed by means of pitched guide banks or other training works, was always necessary upstream of a weir. If the sectional area of this control channel were correctly designed, the velocities generated by floods would keep it free of shoals, and Spring's method of turning the impregnable heads round to face the currents from the embayments appeared to be the best for the purposes. Each case. however, had its special local conditions, to which the training works had to be adapted He thought it was impossible to avoid the construction of training works of some kind, once a weir had been built across a river which had soft banks, and amongst other reasons for their construction was the one, that zamindars naturally would not tamely submit to the erosion of their lands, which rightly or wrongly they attributed to the weir.

The alternative to making a long channel of control would per[illegible] be to have weirs which were *wholly* collapsible. These, by [illegible]ng a greater draw during a high river, would cause shoals to b[illegible]e thoroughly scoured away during floods, but even so short [illegible]nel of control, to give direction to the "draw" would be necessary.

There was a similarity between a river conveying water, but constricted by a weir, and a rubber tube conveying air, but constricted by a bit of string tied round it. Just as the air pressure expanded the sides of the rubber tube above the constrictions, so the scouring action of the water, induced by the shoaled and convex river bed, caused erosion of the banks above the weir. Like the analogies between electric and hydraulic phenomena, however, this analogy must not be pressed too far, because air differed from water in being much more compressible and elastic. Training works, by stiffening the banks above the constriction, prevented those alterations of sectional area which would otherwise occur.

MR. NICHOLSON, in reply, said he was glad the paper had the desired effect of bringing out the views of different members, but he would draw attention to the fact that the statements in the paper were not his own views

In reply to Mr. Harvey's question as to why the obselete method of putting in spurs at much great expense had been adopted, the author could only say that it was considered that spurs were intermittent guide banks. Geometrically this was so, but whether they practically fulfilled the condition. was another matter, which the future would show. The object was to keep a straight channel from Spur No. 2 to the undersluices, to enable efficient scouring to take place upstream. The position of the spurs was a matter of considerable controversy, and the

Local Government had decided to put them in where they now stood.

Rai Bahadur Bishambar Nath had dealt with the case at Dera Ghazi Khan, but it would appear that there they had either been very short of stone, or else that the apron was made too small. When the side slope pitching on a bund or spur stretched or opened, it was usually accepted as being the first sign that the apron had not been correctly proportioned to the scour. Instead of using the moonj trangars, as mentioned, the author would suggest that the use of galvanised wire netting for crating the stone would have been much more satisfactory owing to ease of manipulation, strength, and durability. Netting four feet wide, 14 B. W. G., and four inch mesh, at Rs. 17 per fifty yard roll, was obtainable in the Indian market, and had given satisfaction at Rupar.

Mr. Schönemann had said there was no necessity to put in any spurs, but the fact was that they were losing control of the river by the undersluices. In the cases where the condition of the river had been referred to as favourable, it would be noted the main channel went straight for the undersluices enabling efficient scouring to take place. The spurs, it was considered, would act as a guide bank, and, as they were on a concave curve to the river, the main stream would follow the curve up to Spur No. 2, and then continue to flow past Spur No. 1, to the undersluices when they were open. Effective scouring of the shoals, which tended to form above the undersluices from the method of regulation adopted, would be ensured in this way.

The question of the change of slope in the river at different times was a complex one. The present increase in the slope above the weir, as compared with 1874, was due to the deposit of shingle in the bed of the river for miles upstream. At Patial the river bed was now four feet higher than it was in 1874. Mr. Schönemann's statement that, if steepening the slope of the river tended to cause it to lengthen its channel, flattening its slope would tend to shorten it, seemed to be open to doubt, especially with silt charged water. He considered that it was essential that something should be done to ensure control of the river even at a high cost, as the loss, on account of silt entering the canal, owing to ineffectual scouring by the undersluices, was more than would be imagined without going into the actual figures. There would further be a good revenue from the land which was incidentally reclaimed between the spurs. This was of excellent silt, and gave good crops of sugarcane.

He considered Rai Bahadur Baij Nath to have been fortunate in that he had been so many years at Rupar and yet left before the trouble arose. The erosion above Alampur had not been increasing rapidly, but the shoaling above the sluices up to Spur No. 2 had not been seriously noticed. It was this objectionable condition which had necessitated the new training works. The Rai Bahadur had stated that from 1907 to 1912 the surveys shewed that the conditions opposite spurs Nos. 1 and 2 had been improving, and that since that new spurs had been put in, the condition had been aggravated. It was, however, entirely a question of level. Prior to the new training works being consructed, the silt shoals were covered with bulrushes above water surface, and visible to the eye. Now, owing to the new channel having been scoured out, along the line of the new spurs, the shingle, moved out of that length of the river bed, had not yet passed through the undersluices. These shingle shoals were not visible to the eye, but nevertheless they existed below the surface as was shewn by probing, and he wished to lay stress on the fact that, in dealing with a river carrying shingle, consideration of the condition of the river had to be carried beyond what was visible on the surface.

He agreed with Mr. Wadley's idea that a channel of control should be formed, and that in many of the Punjab weirs too large a width of waterway had been allowed. The chief difficulty had been to maintain control with a discharge varying from 5,000 to 700,000 cusecs. The advantage of having training works on a curve was that the river invariably kept to the outer edge thereby fixing its own position.

With reference to Mr. Gibb's remarks, he agreed that there was nothing definite laid down as to what was wanted at a headworks. Nearly every one had his own views, and unfortunately, with continual changes in the administration, no one was left to work out a line of action to completion. There was no doubt about the fact that, with a high discharge, a river could keep to a larger radius than with a low discharge. At Rupar, during the last monsoon, the river in flood silted up between the spurs, almost to the curve they were on. The low river in the winter worked to a much smaller radius and, embay ing between each of the spurs, scoured out the silt deposited in the hot weather and carried it on to the canal, and it might be necessary to take some steps to prevent a low river embaying and passing on silt in this way.

It was the question of silt control in training a river for a canal headworks that made it a far more delicate question than training a river for a railway.

COLONEL CRASTER, in summing up, said that the Congress was very much obliged to Mr. Nicholson for his paper and for the able way in which he had replied to the criticisms. Railway engineers, Colonel Craster continued, were not giving up Bell's bunds in favour of spurs as had been suggested, but personally he did not advocate spurs in preference to bunds. In special cases they had adopted T-headed spurs, *e. g.*, three miles below the bridge over the Sutlej at Adamwahan, where the river was rapidly eroding its bank, and threatened both the railway and an inundation canal ; and the object of the spur, placed some two miles above the most threatened point, was to fend the river off, and to induce it to enter a straight channel. To return to Bell's bunds, the problem, from a railway point of view, was to constrict the river and pass it through a bridge in a channel of uniform section ; no question of providing against the deposition of silt entered into problem. To meet the concentrated attack of a river the heads of Bell's bunds were made of solid stone. Rai Bahadur Bishambar Nath had raised the general question of the efficacy of such bunds ; but, if no considerable apron had been provided, this would account for the erosion mentioned. Railway practice was to provide an apron varying in width from fifty to a hundred feet, and in thickness from four to six feet, the lower portion being of small stuff, with large stone above, and a solid head. Protected thus, any attack of the river could be awaited with confidence, and the cost of maintenance spread over a series of years was small, though, from time to time, the reserve of stone had, of course, to be recouped.

Referring once more to the Rupar works, Colonel Craster said he quite understood the necessity for starting the training works so far upstream. Personally, he thought some of the spurs would have to be extended and connected up, but, of course, this was a question which must be decided by the irrigation engineers.