SOME NOTES ON THE RESULTS OF RIVER TRAINING IN THE PUNJAB.

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The Beas, Sutlej and Chenab Rivers have each at various points been trained by Bell bunds according to the principles laid down in Sir Francis Spring's Paper.* A table is attached in which the chief railway bridges of the Punjab have been tabulated, and their spans, together with the dimensions of their guide bunds, if any, noted.

This paper will only deal with the new bridges over the Beas, Sutlej and Chenab, as these rivers have had their waterways trained to pass through a restricted channel. It cannot be said, however, that finality has been reached in the economical design of training works; but the methods of the last ten or twelve years are so much in advance of what was done before in the direction of reducing waterway, and training a river into a defined channel, that it appeared to the author that a few notes on the results obtained would be of interest to the members of the Congress.

The training of a river for railway purposes has a different object in view from that desired by the Irrigation Department when training for the headworks of a canal, but the main point is the same, *viz.*, to keep the river in a definite channel. The result aimed at for a railway bridge is to obtain a scoured out channel of uniform depth, and of constant cross-section. Of course by uniform depth is meant, uniform depth across the width of the river at the bridge site, and this depth will vary with varying flood levels.

The Beas Bridge.

The Beas river drains about 7,140 square miles; and is bridged at Wazir Bhular, twenty-seven miles from Amritsar. The original bridge consisted of twenty-nine spans of 111 feet centre to centre of wells, 12'-6" diameter, with average depth of 44 feet. This bridge was begun and finished in 1869. Considerable difficulty was experienced in turning the river into the bridge opening, and in a few years floods caused serious damage. Piers Nos. 25 and 26 were displaced, while Pier No. 28 fell upstream, and the whole together with

* Railway Technical Section Paper

600 feet of approach bank, were washed away. The R. L., of the H. F. L., was 739·86. To crown all, an engine, fuel truck, two carriages, and a brake van fell into the breach and were engulfed, but no lives were lost. The bridge was then lengthened to thirty-two spans of 111½ feet centres, and two of 131 feet—these two latter being put in to avoid difficulty in sinking new wells near the old ones. The bridge still exists as then reconstructed, but has been a constant source of anxiety to the engineers responsible for its up-keep. An enormous annual expenditure has been necessary to protect the piers from scour, though of late years this has been remedied by the use of turtle backs as described in Technical Section Paper No. 93 of 1901-1902.

In 1910 it was found that it would be necessary to increase the strength of the girders, but it was finally decided to build an entirely new bridge upstream, consisting of nine spans of 200 feet with Bell bunds, details of which are given in the Table.

A map showing the state of affairs in July 1913 is attached. The trend of the river is noticeable, the tendency to cross from the right to the left bank being apparently due to the difference in length of the training bunds. The same tendency was noticed at Marala, where somewhat similar conditions prevail.

Diagram A shews the depth of scour during different floods. The peaks at piers Nos. 2, 3, 4 and 5 are due to the stone placed round the piers, and seem to prove how undesirable it is to place stone in this position, as it reduces the effective waterway and prevents a uniform scour taking place. Comparing this diagram with that for the Chund bridge, (Diagram B) the difference is very marked. In the Chund bridge the bed of the river is approximately uniform, whereas in the Beas bridge it is a series of hollows and peaks. No doubt the existence of the old bridge downstream had a marked influence on the scour at the Beas bridge, and it seems that the river has not yet reached its permanent channel.

The Sutlej Bridge at Phillour.

The Sutlej drains about 23,000 square miles above the site of the bridge at Phillour. It was originally intended to have thirty-eight spans of 100 feet, but during construction this was increased to thirty-eight, and in 1870 it was opened as such; the bridge consisting of fifty-eight spans each 99 feet clear

DIAGRAM A.

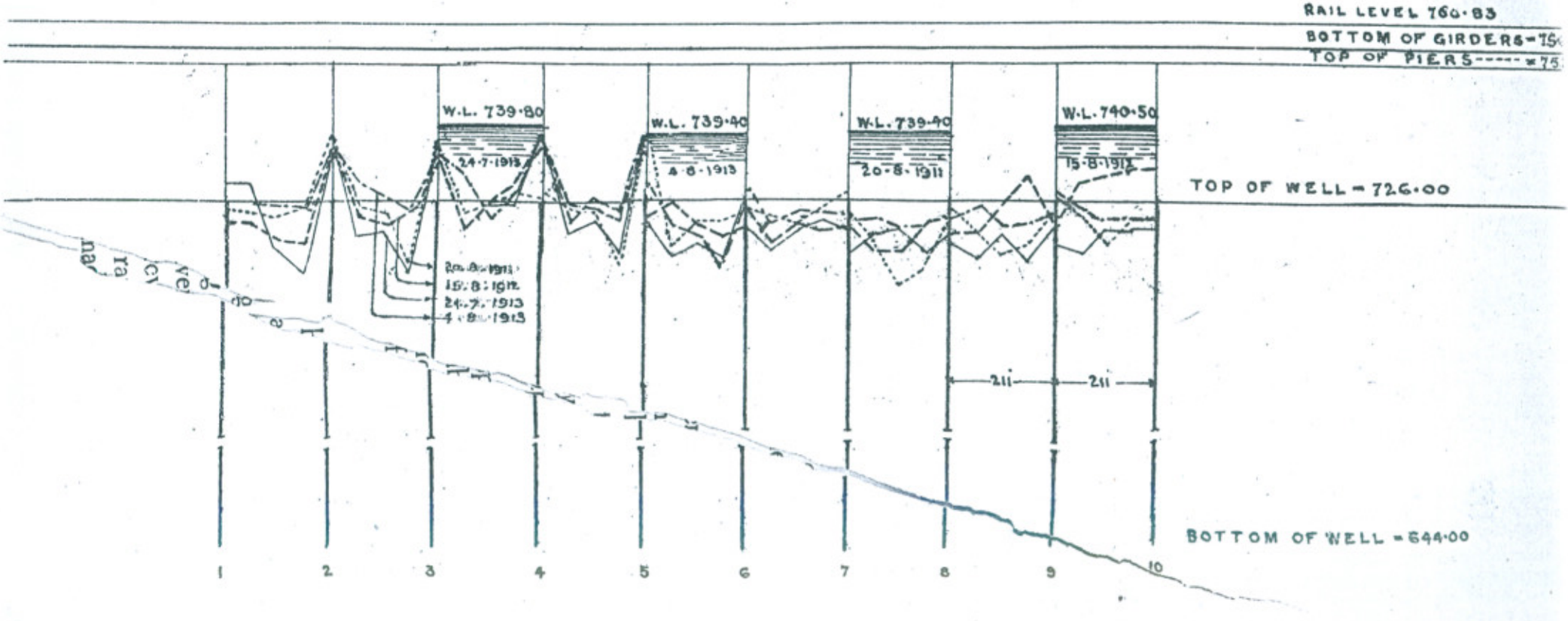
BEAS BRIDGE

9 SPANS OF 200 FEET

LAHORE ←

SCALES { HORIZONTAL 400 FEET = 1 INCH,
VERTICAL 40 FEET = 1 INCH,

→ DELHI



waterway with the bottom of the girders 8·85 feet above H. F. L.

In 1872 serious damage was caused by floods, and piers Nos. 16 and 17 fell over, due to a scour of 37 feet. The repairs resulted in three spans being converted into four spans of 84 feet ; and with subsequent alterations the bridge stood in 1907 with forty-three spans of 111 feet over all, and four spans of 84 feet.

In the case of this bridge, as in the Beas, the protection consisted of loose stone piled round the piers and abutments, together with a few spurs placed where convenient.

The new bridge consists of eleven spans of 200 feet, with the piers sunk to a depth of about 85 feet. Upstream there are two Bell bunds each 2,000 feet in length, while downstream the bunds are 500 feet long. The training bunds are of equal length, and it seems a moot point whether this bridge could not have been shortened by at least another span.

The Chenab Bridges.

The Chenab river is bridged in two places, one near Wazirabad, by twenty-eight spans of 142 feet; the other at Chund, by ten spans of 200 feet.

The first bridge, although it has been shortened, has not been entirely trained by Bell's bunds. The original system has been fully described by Sir Francis Spring in his paper to which reference has already been made, and the conditions there still give anxiety as to what the river may do. It is not proposed to go further into the matter in this paper.

The bridge at Chund consists of ten spans of 200 feet, with Bell's guide bunds, as shewn in the Table. It was built during the years 1903-1905 and therefore has now been working for eight years. The results of scour are shown in Diagram B.

During a flood in 1909 the right hand guide bund was breached, the river taking a course approximately in "the worst possible position" and attacking the rear of the bund just behind the rear apron. Owing to the staff being unable to get to the place in time, the river cut away the bund and broke through; it was however prevented from entirely cutting away the bund, and as the flood rapidly decreased, the breach was filled, and the bund again made up. Eventually the rear

apron was extended further back, and since then there has been no further trouble.

It may be remarked here incidentally that the bunds have straight noses. The depth of scour during 1909 at the nose was over sixty feet. Diagram B shews the scour during the floods of 1911-12-13 and special attention is drawn to the approximately uniform scour over the length of the bridge.

PART II.

When considering the question of designing training bunds, it has occurred to the author that there are several points on which more definite information is required, and it will be useful to tabulate these and discuss them in order—

(1) The position of the bridge in the *Kadir*.
(2) The length of the training bund.
(3) Whether the nose of the bund should be straight or curved.
(4) Whether stone should be put round the piers or not.

These points at the present moment are subjects of variations of practice and much difference of opinion, and for this reason they are brought to notice, in the hope that a useful discussion may take place, and a professional opinion be obtained as to the best practice,

I.—The position of the bridge in the Kadir.—It is evident that the position, considered from the view point of the training of the river, can vary very considerably. We may have the Kadir—

A.—With two low banks,
B.—With one low and one high bank,
C.—With two high banks.

There are two possible main positions in case *A*, *viz.*, at (1) either bank (2) in the centre.

B.—Three possible main positions, (1) near the low bank, (2) near the high bank, (3) in the centre.

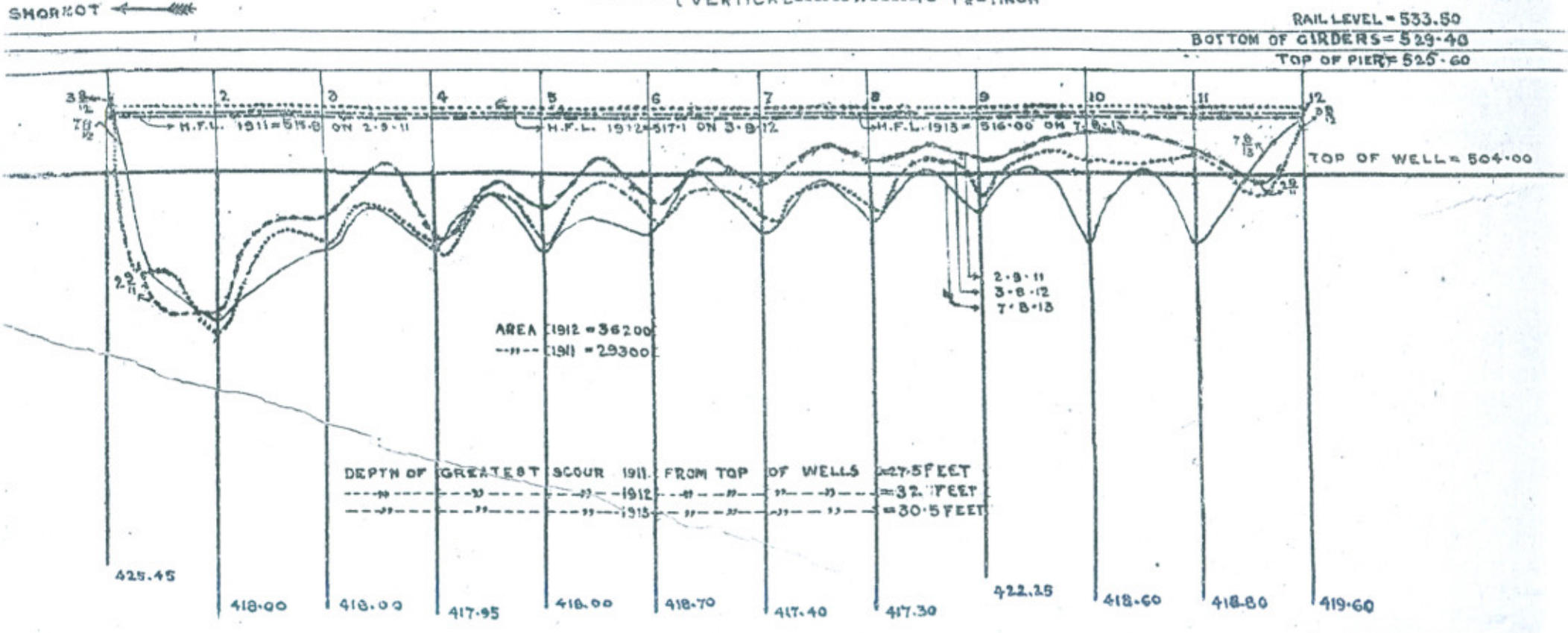
C.—Same as A.

Excluding local peculiarities, the question is, whether any general rules as regards the position of the bridge can be laid down. Can we say the position entirely depends on the low water channel? For examples in each case:—there is the Rivaz bridge at Chund actually built approximately in the centre of the Kadir, while the Beas bridge is built near the high bank, and the Sutlej bridge at Phillour also about the centre.

RIVAZ BRIDGE (OVER CHENAB AT CHUND)

11 SPANS OF 200 FEET

SCALES { HORIZONTAL SCALE 400 FT = 1 INCH
VERTICAL ------ " ------ 40 FT = 1 INCH



If the limiting radius of the curve of the river is taken into account, it would appear that in any case the better position is near one of the banks, and then only on one approach is it likely that subsidiary retired bunds will be required. One more point in this connection is, what should be considered the " safety distance," *i.e.*, how near may the river be allowed to approach the toe of the railway, and this leads us to consider :—

II.—The economic length of the training bund :—This is a very complicated question. Sir Francis Spring gives the empirical length as equal to the length of the bridge, but several engineers are of opinion that this is too long. It is certain however that if the two bunds are not of the same length, the river will be forced over to the longer bund at the bridge site. This is what Irrigation engineers aim at, and is well illustrated by the map of the Beas bridge.

It is very necessary to ascertain, what are the controlling factors determining the length of bund. It has been said that the length required should be such as to ensure a uniform flow through the bridge, but the author is of opinion that however desirable this may be from a theoretical point of view, it is an impossible condition to lay down, because at present we do not know, and it is doubtful if we ever shall know, what is the smallest discharge in the case of any river that will produce a uniform scour.

If this be considered the only controlling factor, before a definite solution can be found it will be necessary to carry out a series of observations consisting of taking velocities and soundings across the river between the guide bunds during heavy floods. This of course would be quite possible with a motor boat capable of moving against the flood. It would however require a trained staff and take time to carry out, but the results would undoubtedly be well worth the time and expense incurred. From such soundings at our existing works, a position would be found where the river bed approached to a uniform depth with a given discharge. It is probable that this position would vary with the velocity, and probably the higher the flood (in other words the greater the velocity) the nearer would this position approach to the bridge site.

The length of the training bund, moreover, must, be such that the river will not outflank it. It follows therefore that the length is dependent on the limiting radius of the river. In the

most recent bridges built, the length of the training bund has been reduced to half the length of the bridge, and Mr. Bagley informs me that so far it has been most successful, but time will show if it is advisable to reduce the length to this extent.

III.—Should the nose of the guide bund be straight or curved ? Sir Francis Spring recommends a curved nose and gives the necessary dimensions, but all the guide bunds on the North-Western Railway have been built with straight noses. The reason given for the straight nose is that there is less swirl set up, and consequently less scour will take place. This is however hardly borne out by facts, and at Chund soundings of over sixty feet were taken during flood, while the author has just received sections from Shershah showing a sounding of over seventy feet. In both cases the stream was approaching the "worst possible position."

DISCUSSION.

MR. HARVEY, in introducing his paper, pointed out that any undue extension of the training bunds upstream also induced the position of the section of uniform scour to move upstream, whereas the ideal length of bund would be one long enough to prevent out-flanking, and at the same time of such length as would induce the uniform scour in the bed of the river to take place at the bridge site.

He also advocated a curved head to his bunds in preference to a straight head, as it did not increase the scour on the face, while it afforded better protection at the back.

He further considered it a mistake to use stone pitching round the piers ; when these were designed of sufficient depth to take the maximum scour why waste money in stone pitching ?

COLONEL CRASTER said that at the new Beas Bridge the "peaks," to which the author drew attention,* were very interesting, but he did not agree with him that it was undesirable to place any stone round a pier. His own experience had been and in this he thought others could bear him out, that the Punjab rivers, when running low, tended to hug one bank or the other, sometimes both, with their main cold water channels. When the flood water came down the water gradually ate away a deep channel from one channel to the other, and if it met with any obstruction, such as a pier, the channel was deepened. In the immediate neighbourhood of hat obstruction, whilst the surrounding sand remained some feet higher.

The section of the Chenab Bridge shewed clearly what he suggested state of things was also to be found at that bridge. Most valuable was of opinion therefore that the provision of a small stone protection round each pier was desirable, and the practice was to lay a width of eight to ten feet, and six feet, round piers of spans from 80 to 100 feet. The object was to cause the river in the earlier phases of flood to cut the sand in the centre of each span rather than in the neighbourhood of the piers, and in this way to secure a channel as possible in a minimum of time, with a uniform through all spans, so that no part of the bridge would do more than its fair share of work.

The author had referred, in his remarks on the training and control. William John's at Garmukhtesar, training system is hands ; it has unparallel guide banks es, with the advanfurther upstream, if banks of the bridges ab at Chund, Beas at pindi had been recently to the existence of the old bridge downstre

* Page 150.

scour at the new railway bridge. It might interest the Congress to know that as a result of years of maintenance on the old bridge, the piers, when they were abandoned by the railway, stood in islands of stone about thirty feet wide at the top, with side slopes of one to one ; whilst the whole bed had been covered with a stone flooring of unknown thickness, extending from a line some 65 feet upstream to 120 feet downstream of the piers. The levels of this flooring varied greatly, and very curious pot-holes were to be found, the bottom of the lowest being some five feet above the bottom of the well nearest to it. The beneficial effect of the stone protection round the piers was thus clearly proved, but owing to the steep slope of the sides of the islands, it was necessary to keep continual watch in flood time, and to replace stone on the slopes as it was scoured away. For several years it had been the practice to throw single stones on to the slopes by hand, but it was evident that with the velocity of the flood, such stone would probably be carried away and come to rest on the bottom several yards below the bridge. Accordingly for the last three or four years of maintenance, stone was enclosed in camel nets, of such a size that the total weight could be handled by men standing in the water. The nets with stone were pushed as far down the slope as possible, and their weight ensured that they would not be carried away, by the current, and the maintenance of the island sides was greatly reduced.

With regard to Part II of the paper he entirely agreed with Mr. Inglis that, if there was a choice, the better position for a bridge was near one of the high banks to save work, but in practice the engineer had not always a free choice ; and it had been the experience that when they had shortened their bridges, within three years after the works had begun to operate, complaints were received that the bridge works were causing floods and damage. The general idea seemed to be that the bridge must raise the flood level, whereas they knew that what it did was to lower the bed level, thus benefitting rather than injuring her side by fixing the channel at that point for a time.

He was not prepared to hazard any hard and fast rule as to the length of the training bund, he agreed with the author that wherever possible, the bunds on both sides should be opposite each other ; it seemed pretty clear that they had hitherto failed in determining their lengths, and that it was necessary to find that a bund little more than half the

total length of the bridge would, in ordinary Punjab conditions, suffice. This matter was of considerable importance, as the mole heads were of solid stone, and it was a serious matter, once these heads were made, to have to shift them.

The tendency of modern practice in regard to the slope of the nose of the mole head was to flatten it out, as it was less liable to attack. On the N. W. Railway it had also been found that it was advisable to raise the top of the earthen bund to eight feet above H. F. L., whilst the stone protection was carried to six feet above the same level. In this way a margin of stone was secured, so that even if no one was present when a slip of stone occurred on the submerged slope, there was other stone in position which would probably slide down and replace it.

The speaker added that he was not prepared to agree with the author in his preference for a curved head to his training bund. A straight flow was very desirable, and the protection of the back of the bunds had not been found an expensive item in the case of the old bridges. In Bell's bunds, as originally suggested, the distance between training bunds on either bank at the heads was to be made less than at the bridge site, but no one had as far as he knew actually built training bunds on this plan.

MR. SLEIGH said that the main object of the paper was evidently to collect information from the members of the Congress as to the design of bridges across Indian rivers. The late Mr. J. R. Bell's original idea for training Indian rivers was a bottle necked arrangement, which had been fully explained in a Government of India Technical Paper.*

Sir Francis Spring modified this principle, and suggested parallel guide banks with curved heads, and a most valuable paper had been written by him on river training and control.

Sir Francis Spring, in his preface to Sir William John's paper on the construction of the Ganges bridge at Garmukhtesar, remarked that, "our Northern Indian river training system is undergoing a process of evolution at Mr. John's hands; it has undergone an important development in straight parallel guide banks being substituted for the original curved ones, with the advantage of the possibility of extending them further upstream, if necessary." On these priniciples the guide banks of the bridges across the Ganges at Garhmukhtesar, Chenab at Chund, Beas at Beas, Sutlej at Phillour, and Sutlej at Gidarpindi had been recently

* *Vide* Government of India Technical Paper No. 2 (*b*).

built. The new bridge across the Jumna River at Kalanour was the subject of a paper which the author regretted he had been unable to get ready for that year's congress. On this bridge the guide banks were funnel shaped, at an angle of 97° 27' with the centre line of the bridge ; this was done in order to make use of an existing bund ; the mole heads were a straight and not a curved continuation of the guide banks, and the design of this bridge might therefore be considered to be founded on the Garhmukhtesar principles. Parallel guide banks with straight mole heads had been an unqualified success, so there was little to be said about that design ; the excessive scour mentioned on page 154, was not due to the straight mole heads, but in all probability to some local feature of the river

One of the points on which discussion was invited was the question of the length of the guide banks. Sir Francis Spring recommended for the length of the upstream portion of the guide bank, the addition of 300 feet to the limiting radius of the river, in order to ensure there being still water against the approach banks. From a theoretical point of view this would be an ideal arrangement, but this state of affairs could not be obtained in actual working conditions, for though there might be no stream, yet erosion of the approach banks must take place owing to wave lap. If therefore the approach banks had to be protected from wave lap by strong and solid turfing, or rip-rap pitching, why not allow a slight flow, say up to four feet per second, along the banks, instead of increasing the length of the guide bank by three hundred feet to ensure still water ? It would be as well to subtract three hundred feet from the limiting radius of the river ; or perhaps making the length of the upstream portion of the guide banks only 0·6 × length of the bridge would be sufficient for bridging the rivers of the Punjab.

Another point brought forward in the paper was the question of pitching the wells of the piers with stone. This of course entirely depended on the depth of the wells below the winter low water level of the river.

Mr. Bell advocated in his paper on the waterway and spans for bridges that the depth should be $6\sqrt{\text{span}}$. This was the principle on which the Ganges, Chenab, Beas, Sutlej and Jumna bridges had been designed, the clear spans in every case being two hundred feet ; and on all these bridges, except the new Jumna Bridge, a quantity of stone amounting to about 20,000 cubic feet had been put round the wells. On the new Jumna

Bridge, particular precautions were taken to clear the wells of the piers of all obstructions, as experience obtained from the other recently constructed bridges had showed that pitching stone protection was not required, where the depth of the wells exceeded eighty feet.

Judging from Diagram A * it would appear that pitching stone round the wells was unnecessary, which was quite true, but, reading the paper one might also be under the impression that stone was only placed round Nos. 2, 3, 4 and 5 wells of the new Beas Bridge. This however was not the case, as exactly the same quantity of stone was placed round piers 6, 7 and 8, but these piers received the full force of the stream during the summer of 1909, prior to the construction of the left guide bank, and the stone therefore sank. No mention was made of the stone round the wells of the Chund Bridge, though a considerable quantity was actually put round each well, but this stone had also sunk in the way it was intended it should. The sooner the stone around piers 2, 3, 4 and 5 of the new Beas Bridge was removed, the better would be the flow through the bridge. The removal could be easily done, as the stone was only six feet in depth when originally put in, and had scarcely sunk at all.

The idea of straight and parallel guide banks was not entirely Sir W. John's, part of the credit being due to Mr. Bagley, who had now recommended, for properly restricted rivers, a shallower depth of wells with pitching stone placed in a concentric oval ring around the wells, and spans of one hundred feet clear instead of two hundred feet. This design was very favourably commented on by Sir W. Johns in his last report on the North-Western Railway, while he held the position of Senior Government Inspector of Railways.

That any proposal of Mr. Bagley's should receive every railway engineer's attention, was evident from the fact, that whereas, to his completion of the new Beas and Sutlej bridges with parallel guide banks, three hundred feet upstream of the old bridges, these old bridges, on wells, forty feet deep, had been a continual source of anxiety to the Open Line engineers, but, from the date the new bridges were opened in 1910, not a single stone had beed dumped round the wells of the old bridges, yet the piers were standing and would continue to do so. Formerly truck loads of stone had to be dumped round

* Page 150.

the wells to keep them from being scoured out during the summer floods. Sixty feet in depth of wells, with 10,00 cubic feet of stone round each well, should be ample for a properly constricted river with a sandy bed.

The paper suggested that the new Beas and Sutlej Bridges were too long by an extra span. Mr. Bagley, when making the calculation for the waterway in the project estimate of these bridges, added an extra span to the calculation, the reduction in waterway from that of the old bridges being so great that it was incumbent on him to be on the safe side. In the new Jumna Bridge this extra span had not been added.

For a rough working rule the length of a bridge should be $\frac{1}{200}\times$ the maximum discharge of the river.

This would make the length of the—

Ganges Bridge at Gurmukhtesar	...	1500	instead of	2200 feet.
New Beas Bridge at Beas	...	1500	,,	1800 ,,
New Sutlej Bridge at Phillour	...	2000	,,	2200 ,,
New Jumna Bridge at Kalanour	...	1250	,,	1400 ,,

In conclusion, the following suggestions were made in regard to item (I) Part I, page 152, *i. e.* the position of the Bridge in the Kadir.

A. If the Kadir had two low banks :—

The position of the bridge could be anywhere across the winter channel, and this was really the most convenient site, for in one working season the wells, guide banks, and approach banks should be completed.

B. If the Kadir had one low and one high bank :—

This problem had to be solved in the new Beas Bridge—the obvious solution was to place one abutment of this bridge close to the high bank, but as the winter channel, which is about 300 feet in width, and $4\frac{1}{2}$ feet in depth hugged, the left bank, it was found uneconomical to divert the channel for a distance of 1,500 feet across the river bed. If the diversion of the channel was simple, the site of the bridge should be, excluding local peculiarities (*viz.* bends in the river within a mile upstream of the bridge, &c.), with one abutment close to the high bank.

C. If the Kadir had two high banks :—

In this case it was probable that either the river was flowing in an even channel, or that the banks were incapable of easy erosion ; in either case the provision of artificial banks (*i. e.* guide banks) was unnecessary, and the entire waterway should be crossed with a bridge.

CAPT. ANDERSON described how he had once in the hot weather of 1911 gone by boat from the east mole head of the new Beas Bridge to the Fatto Chak, the opening referred to by Mr. Sleigh. The river was then within about two feet or less of the highest recorded flood level, all the borrow pits north of the railway bank had been flooded, and the road from Dhilwan station to the tahsil was breached. On this occasion there was a strong stream through the Fatto Chak, but this only occurred during the highest floods, and he did not agree with Mr. Sleigh in thinking that this opening had anything to to with the erosion of the left bank below the Beas Bridge.

MR. MACFARLANE said he would like to know something about the down stream end of the training bund ; should it be curved back or finished off straight ? Below the new road bridge over the Ravi he was deliberately cutting back into the left bank in order to get a curved end to the bund and he would like to have Mr. Harvey's opinion on the matter

MR. COLYER wished to know which bunds Mr. Harvey had in mind when he referred to Marala.

MR. FOY asked what should be the length and radius of the curved end of the protective bund.

CAPTAIN BATTYE said the difference between the irrigation problem of coaxing the channel past the canal intake, and the railway engineers' problem of obtaining a uniform scour at a bridge site, was merely a difference in requirements, and that apparently no principle had yet been established for keeping the cold weather flow where it was wanted. He thought it should be possible to theoretically calculate the length of training bunds in order to give a uniform scour at the bridge by applying the principle of the *vena contracta*.

MR. BAGLEY was to his great regret unable to attend the Congress, but submitted a few notes on the points raised by Mr. Harvey. He noted that the paper dealt only with the training works of the new Chenab, Sutlej and Beas bridges, and as he had himself designed all these, he would like to point out that it was not

quite correct to say they were designed in "accordance with the principles laid down in Sir Francis Spring's paper". They were "*Bell bunds*", with modifications in details worked out by Mr. W. A. Johns and himself in 1898, when they built the Gurhmuketesar Bridge over the Ganges, and they differed in some respects from Sir Francis Spring's recommendation.

The most important differences were the adoption of straight instead of curved heads, and a preference for narrower and deeper aprons, to which he would return later.

With reference to Part I of Mr. Harvey's paper, giving the history of the bridges, the chief lesson to be learned was the trouble and danger involved in making the bridge too long as it allowed of the river wandering in all directions, and taking protective works sideways, at the most destructive angles. The first *essential point in designing a railway bridge over a Punjab river was, to reduce the waterway allowed to the minimum that would safely take the highest flood.* The damage done to the guide bund at the Chenab Bridge at Chund in 1909 was due to the protection at the back of the head not having been carried back far enough. A distance of 500 to 600 feet was necessary. He was somewhat sceptical as to the scour of sixty feet believed to have occurred at the nose of this bund in 1909. The difficulty of making correct soundings was so great, that he came to the conclusion, after seven years of careful enquiry, that most of the records of scour on the N. W. Railway bridges were quite untrustworthy, and that there was no authenticated case of a scour over forty feet in depth.

Mr. Bagley had the following remarks to make on the interesting points raised in Mr Harvey's paper :—

(1). *The position of the bridge in the Kadir.*

It was quite correct that if a permanent or semi-permanent high bank could be found, not too far from the main channel of the river for the time being, it was advisable to make use of it, as possibly reducing the cost of the guide bund on that side, but this happened so very seldom that in none of the six large bridges, which he had had to design, was it possible to utilize a high bank to reduce the cost of training. The bridge, with its two guide bunds, could as a matter of fact be dumped down at *any* point in the Kadir, and the ruling consideration was that it should be placed somewhere about where the river was running when the bridge was built, in such a manner that no expense, or the

least expense possible, would be incurred in training the water through the bridge when built.

His rule was to select a site for a bridge near the lower end of the longest straight reach to be found in the neightbourhood of the desired crossing place, and to begin work on the piers on each side of the existing low water channel, leaving the exact position of the abutments to be fixed so as to include the flowing channel, after the first season's floods, or if this had moved too far away, to move the bridge as far as possible in the same direction, in order to reduce the cost of training the river back to the bridge.

(2). *The length of the training bund.*

Mr. J. R. Bell fixed the length of his guide bund equal to the waterway of the bridge, without any very particular reason, except that some rule had to be made and this appeared to be probably a safe rule. When going into the matter with Mr. Johns however at the Gurhmuktesar Bridge, it struck them from what they saw at various training works which they inspected that this length was excessive, and that the waterway of the bridge had little if anything, to do with it. With some difficulty he obtained sanction to cut down one of the bunds at Gurhmukhtesar "temporarily" to 1,500 feet (instead of 2,200 feet). This had worked perfectly ever since, and there had been no necessity for ever lengthening it. From the further study of the subject during his six years on the N.-W. Railway, he came to the conclusion that the ruling factor was the distance the river was likely to cut in at the back of the head of the guide bund, before it had to "short cut" and change its course more directly through the trained channel. In no case was this found in practice to exceed 500 feet, and it appeared to follow that with another 500 or 600 feet as a margin, the length of the bund need not exceed 1,000 to 1,100 feet.

There was some difficulty in obtaining sanction to this "bold" reduction, but it came by degrees. The length of 1,500 feet was approved for the new Beas and Sutlej bridges, and in the last bridge built over the Sutlej at Gidarpindi (Jullundu-Doab Railway) he had been able to reduce the length to 1,160 feet (to the end of the apron) and to show, by the results of a record flood, that it was a perfectly safe length, and that 300 feet was ample for the length of the down stream section. This applied to the larger Punjab rivers, running in wide sandy beds; but for smaller streams the lengths would differ

according to the nature of the channel, and the depth and velocity of the floods. Probably in most cases, a quarter to half the length of the waterway would be sufficient.

Mention was made, at the discussion, of Mr. J. R. Bell's plan of narrowing the opening between the heads of the guide bunds. His object was to make this opening of the exact length of the *waterway* of the bridge, after deducting the space taken up by the piers. It had not however been carried out in any case, as far as he knew, most probably because the advantage was not very obvious, and would be small at the best.

III.—Shape of the head of the bund.—Mr. Bagley considered it proved to demonstration that straight heads were in every way preferable to curved ends. A glance at a river actually in flood in each case, such as he had frequently seen, would leave no doubt on the subject.

It was not claimed that the maximum possible scour was less with the straight head, but under ordinary circumstances there must be greater destructive action with a rounded head in ninety-five per cent of the cases that could occur from the direction of the current, and the cost of maintenance would thus be always much greater.

With a straight head, taking the current in anything like a "favourable position" (more or less parallel with the guide bund) there would be no action whatever, while with a curved head the current *in any position* was bound to go off at a tangent, and cause pot holes or other destructive action.

The mistake made by Sir F. Spring was in believing that the current on meeting the curve would be "led to flow along" it, and kept from destructive action, but this was exactly contrary to fact, as a current striking a curve on the outer (convex) side, went off at a sharp tangent, thus causing the very twist and eddy he thought it would prevent.

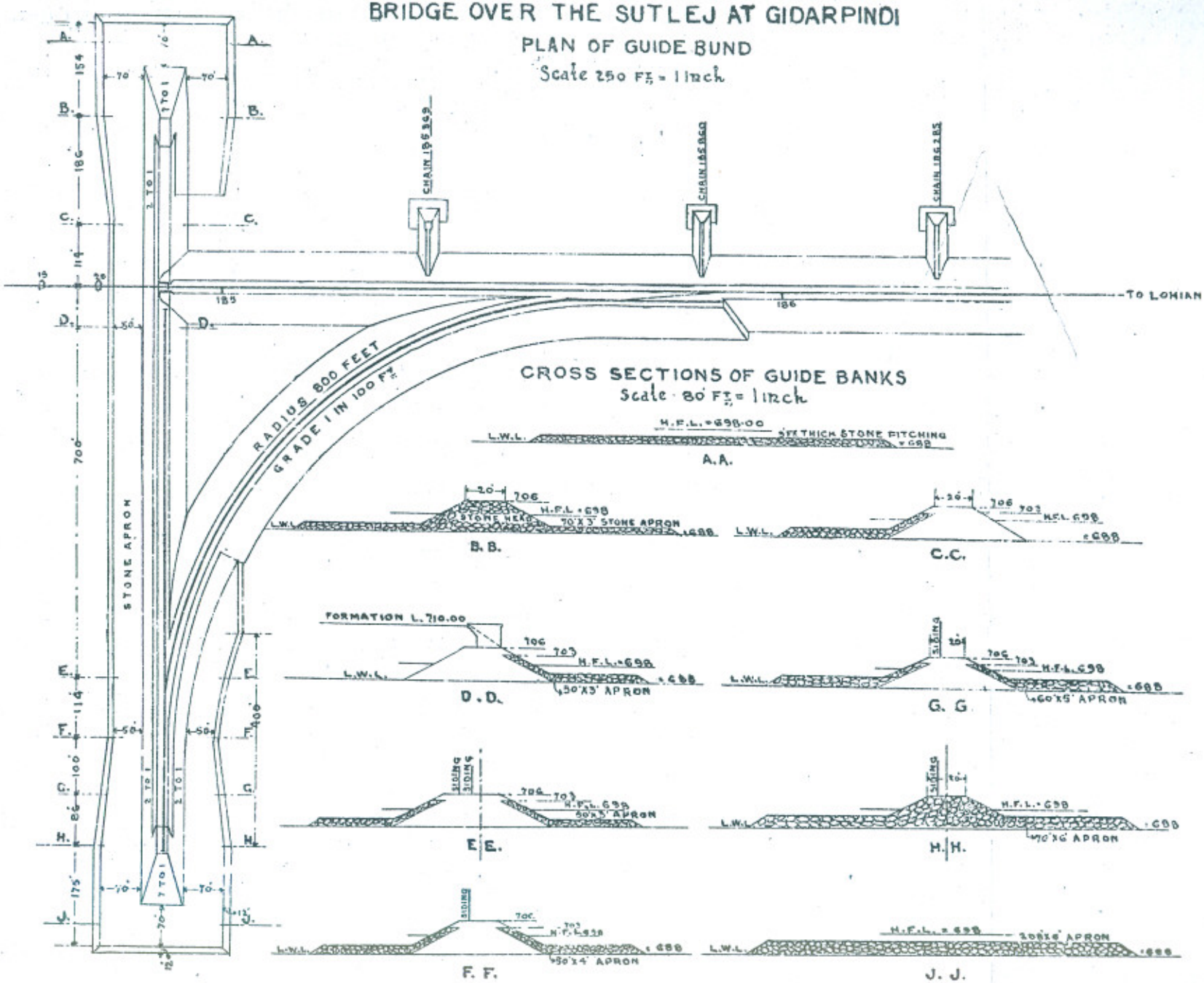
On the inner (or concave) side of the curved head, the curve had a tendency to set up a current along its edge in what would otherwise be still water, and would certainly not have the effect anticipated by Mr. Harvey, of making dead water, and so reducing the destructive action on the head of the bund.

Mr. Bagley attached a sketch showing the general dimensions of the guide bunds at the new Sutlej Bridge, at Gidarpindi which had been designed as a result of his sixteen years study of the subject. They had already been tried by a record flood,

BRIDGE OVER THE SUTLEJ AT GIDARPINDI

PLAN OF GUIDE BUND

Scale 250 Ft. = 1 inch



CROSS SECTIONS OF GUIDE BANKS

Scale 80 Ft. = 1 inch

which had done no damage whatever and had proved, he thought, that it was a good and sufficient design for any Punjab river with about the same depth in floods.

In the case of the Sutlej, the difference between low water level and high flood level was only ten feet. For rivers where the difference was greater he would add slightly to the thickness and width of the pitching of the heads, but would make no other alteration.

MR. HARVEY replying to the discussion, said that the fact that all the piers of the Beas Bridge had stone placed round them only emphasized its uselessness, and asked where was the stone that had been put round piers 6—10 ; evidently washed away, and therefore so much money wasted. As regarded the Futtoo Chak Channel, referred to by Mr. Sleigh and Captain Anderson, it was not apparent how a take-off some way above the bridge could affect the direction of the river at the bridge itself.

In reply to Mr. Foy's question regarding the length and radius of the curved end of the bund, the author stated that he would prefer to adopt Mr. Spring's figures.

In reply to Mr. Colyer the author said he was referring to the East Bund, or the one near the head works.

With reference to Mr. Bagley's remarks on the paper he was very pleased to receive the correction for the first paragraph. They might accept the essential point, as defined by Mr. Bagley, as an axiom, but the question was, what was the best design for the depth of the well and the length of the bunds ?

As regards, the damage done to the Chenab Bridge at Chund, the author's contention was that to prevent the river attacking the back, it was better to curve the end of the bund, rather than put in an expensive apron.

Regarding the scour that Mr. Bagley was sceptical about, he could only say that the depth was measured in his presence at Chund, and, as confirmatory evidence, that was indisputable, he had received plotted sections showing soundings in the comparatively still water, taken during the cold weather at the nose of the bund at Shershah, showing a cold weather depth of seventy feet below high flood level, and doubtless, when in full flood, some scour would take place. He was satisfied that scours of sixty feet and over were possible, and did occur.

Mr. Bagley's notes on the position of the bridge in the Kadir were valuable and interesting, as the experience of an

eminent engineer. Regarding the length of bund, the author thought that it had always been admitted that the waterway had nothing to do with the length of the bund, or *vice virsa*. It was also he thought unquestionable, that one of the ruling factors was that mentioned by Mr. Bagley, which put briefly, was that when the river was flowing at its minimum radius behind the guide bank, there should be no chance of its cutting the railway approach bank. This however was not all, and even Mr. Bagley had not touched on the question of *uniform scour ;* he had fixed on a length of 1,160 feet, based on the minimum radius of flow of Punjab rivers, but was this length sufficient to ensure uniform scour at the bridge ? If not there might be excessive scour at one or more piers, but this question could only be settled by systematic surveying of a bed of the river during floods.

With reference to Mr. Sleigh's remarks that certain bridges had been built with the mole heads of their guide bunds straight, and that these were an *unqualified success*, the author disagreed, and maintained that, at any rate at Chund, if the mole heads had been curved the rear of the bund would not have been attacked.

Regarding what Mr. Sleigh referred to as "excessive scour" at the mole heads being due to a local peculiarity of the river, Mr. Sleigh was quite wrong, as there was no local peculiarity about the river there. The author never said there would be *more*, or even excessive, scour with a straight mole head ; in fact he quoted one example with a straight mole head, and one with a curved mole head, but what he did say was that a curved mole head protected the back of the bund more than a straight one.

Mr. Sleigh's remarks about "wave lap" were fanciful; the water was "still" behind the bunds, and as a matter of fact, the growth of weeds and tall grass was so great as to effectually prevent any such wave lap.

Mr. Sleigh had also quoted a formula for the depth of well foundations ; this was surely with reference to the economic proportion between span and depth of foundation, and was not based on the question of the scour power of the river. As regards the advisability of putting stone round piers, the author had already pointed out that the stone (according to Mr. Sleigh, some 20,000 cubic feet) which had been placed round piers 6, 7, 8, 9 of the new Beas Bridge had been practically all washed away, and the money spent wasted. He had since ascertained that at the Chund Bridge stone was placed round the piers with the

same result. It seemed useless to place stone round piers eighty feet deep, but necessary round piers only sixty feet in depth. He maintained that the latter was a reversion to the old practice of shallow wells, and the very expensive stone protection round them.

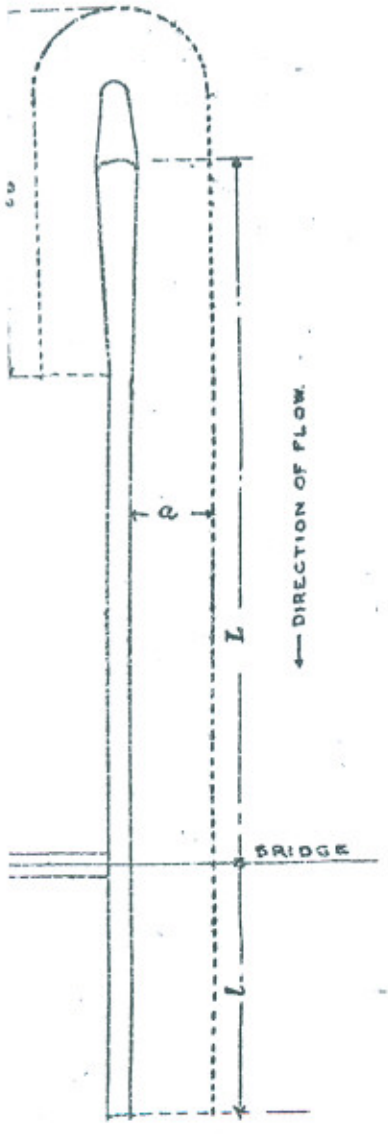
Mr. Sleigh's remarks about no more stone having been placed round the piers of the old Beas Bridge were beside the point and misleading, because the bridge no longer belonged to them, and they had therefore no interest in putting more stone ; and secondly, because Mr. Sleigh did not know what was going on at the old bridge. from which as a matter of fact a lot of stone had been washed away.

Mr. Sleigh gave a formula for the waterway of large bridges, but designs were not as a rule worked on this principle, although the results happened to fit in, and if he read Sir F. Spring's paper he would find full instructions on that point.

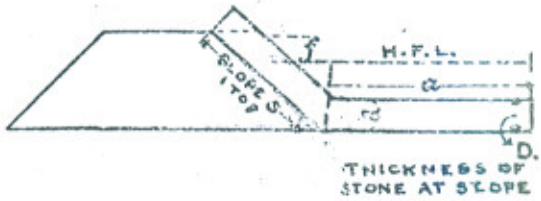
DIAGRAM C.

CROSS SECTIONS OF BUNDS

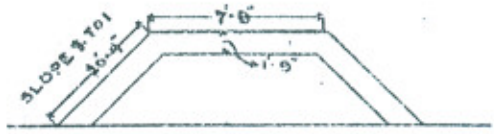
TYPE PLAN OF BUND



TYPE SECTION



RAVI BRIDGE LAHORE



SUTLEJ BRIDGE FEROZEPUR

