MAINTENANCE OF MARALA WEIR, (1912-13).

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Preliminary Remarks.

Object of Paper.

The object of this paper is, first, to describe the working details of the stock-ramming operations on Marala weir in the cold weather of 1912-13, secondly, to analyse the question of the necessity and desirability of those operations both as a particular and as a general case, and (finally), to discuss the question of stability arising from these considerations.

Previous History.

The construction of the weir proper was finished in the cold weather of 1910-11, and in the subsequent cold weather only a little stock-ramming could be done, owing to heavy silt deposits on the fore-apron and talus.

Conditions in November 1912.

In November 1912, some springs were found in the fore-apron or talus below the B line of wells (*vide* fig. 1), and these were ordered to be stock-rammed. Before the stock-ramming was undertaken however it was necessary, for rafting purposes, to close some of the bays by raising the shutters. This resulted in the bays which remained open being to a large extent cleared of silt and debris, thus facilitating an examination of the fore-apron, in which several more springs were discovered. This apparently trivial circumstance is mentioned as a reason for annually scouring silt from a talus before the river supply falls too low, so as to facilitate examination, to reduce the cost of clearance when work is found necessary, and to reduce the hydrostatic pressure on the floor.

Section of the Weir.

The cross-section of the weir is shown in fig. (1). The upstream portion between A line of wells, and the weir crest, consists of an eighteen inch layer of puddle, protected by one foot of dry-rubble, and two feet of pukka rubble-masonry,

with a reverse slope of 1 in 6. This may be called the rear-apron. From the crest to B line of wells, there is four feet of pukka rubble-masonry with 1 in 15 slope, which may be called the fore-apron. These two aprons, constitute, with the crest wall, the permanent section of the weir. From B to C line of wells, $1\frac{3}{4}$ feet of pukka rubble-masonry has been laid on $1\frac{1}{2}$ feet of dry stone to a slope of 1 in 15, and this corresponds to the grouted pitched sections of the Rasul and Khanki weirs. Below C line of wells is the horizontal talus at approximately low-water level. The mortar used consisted of one part white lime, two parts kanker lime and three parts surkhi.

PART I.

Springs.

It was apparent that the springs were rising from within, or below the dry stone, and that their caulking by stock-ramming would entail a large expenditure of material, which would have to grout up the voids of the dry-stone to form a plug, before it could rise and fill that part of the rubble-masonry through which the water was flowing.

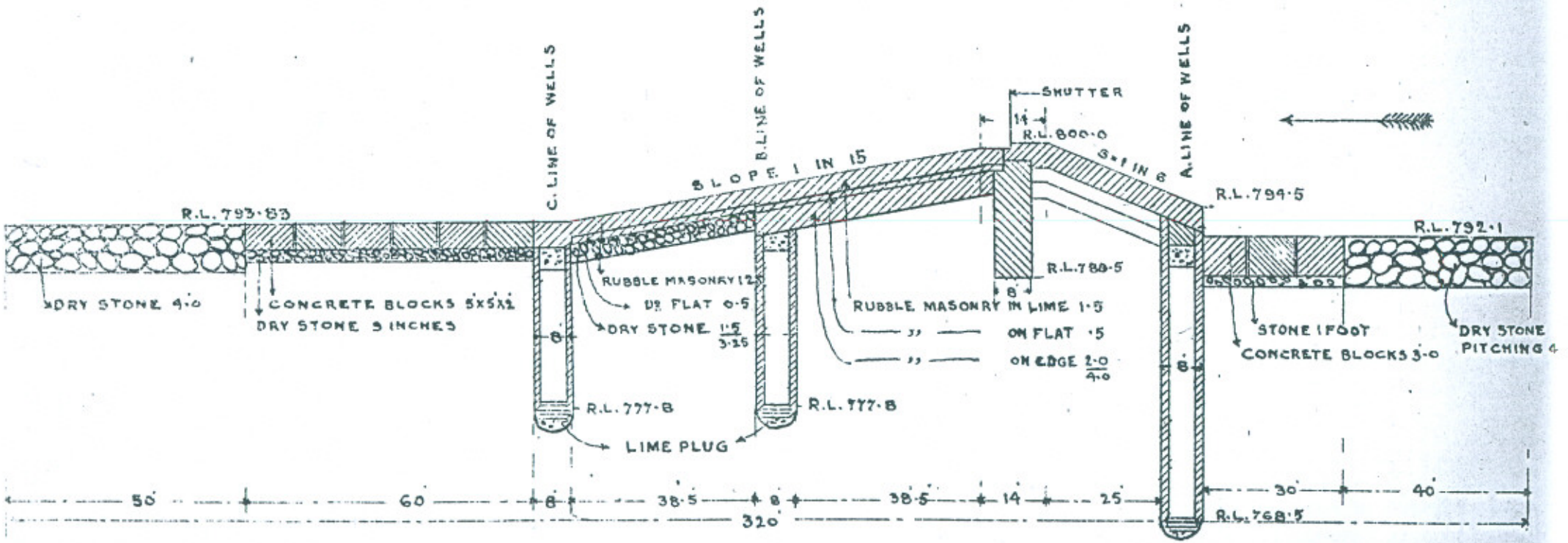
Stock-ramming Pipes.

At first it was thought that half-a-dozen stock-ramming tubes would suffice, and these were made up of $\frac{3}{4}$" iron pipes, about five feet long, on which were fixed annular wooden blocks, each holding a leather disc eighteen inches in diameter, about nine inches from the end of the pipe (*vide* fig. 2). The latter was flattened for the last two inches somewhat like an organ-pipe, with the idea that it could thus be pushed well into the crevice, from which a spring was issuing. This design was soon abandoned however, as it was found that the aperture of the spring was in many cases too narrow to admit even the flattened nose of the pipe, or was more in the nature of a slot than a hole, which would not admit of getting the pipe in at close quarters, and thus leaving spaces for the ready egress of the slurry. The contraction at the mouth also caused the slurry to block the pipe very quickly, while owing to the end seldom penetrating to the full nine inches into the aperture, on account of the irregular nature of the rubblemasonry, a large space was left at 'A' (fig. 2), between the floor and the leather disc, which it was necessary to fill with slurry before the hydrostatic head in the pipe could produce a ramming pressure on the slurry in the spring. This caused a waste of material.

GENERAL SECTION
OF
WEIR ACROSS RIVER CHENAB AT MARALA

Scale { HOR 1/500 / VER 1/200

FIG. 1



The next development was a cylindrical tube with the leather disc fixed flush with the end. The wooden block was replaced by two tin discs, each four inches in diameter, soldered to the tube above and below the leather (*vide* fig. 3).

Meantime further silt-clearance had shown that instead of six tubes, sixty would probably be required, the work being urgent on account of the probability of freshets. There not being sufficient iron pipes in stock, the service of the ubiquitous oil-tin was requisitioned, and tubes were made by bending strips of tin round a rod and soldering them up.

As work proceeded, it became apparent that for the eight bays with over a thousand springs in each to be attacked at once, at least two hundred tubes would be necessary ; and for the sake of economy, old tarpaulins were cut up and used double in place of the leather. This proved successful, and new canvas, of which a single thickness was found to be sufficient, was purchased, and a saving of Re. 1-8 per tube thus effected (*vide* fig.4).

The use of flexible canvas discs led to another small economy, *i. e.* the sloping of the puddle ring, (fig. 5), down towards the mouth of the spring, thereby saving the cement A in fig. 2, which used previously to accumulate below the leather disc. This saving is not so trifling as might appear at first sight. An actual comparison showed a difference of fifty cubic feet per thousand springs, equivalent to Rs. 180.

Stock-ramming.

The actual process of stock-ramming was as follows :— The aperture of the spring, if not already well open, was dressed by a mason assisted by a cooly. The lower puddle ring about two feet diameter and two inches high outside sloping down to $\frac{1}{2}$" at the mouth of the spring, was at first made by a mistry, and subsequently by an ordinary cooly trained to the work. An opening (B in fig. 6) was left in the side, in which was laid a stick a foot long and one inch diameter to prevent the opening from becoming choked. The canvas flanged-tube was then placed upright in the centre, and the disc covered with puddle from three to four inches thick, forming a water-tight joint with the lower puddle, the water escaping in the meantime by a space alongside the wooden stick.

The slurry was mixed while the coolies heaped up sand over the puddle to a height of about two and a half feet. When

all was ready, the stick was withdrawn, the escape-hole quickly blocked with puddle, and slurry poured in through a funnel at the top of the tube, the stream being kept as continuous as possible and being manipulated at intervals by iron ram rods (fig. 7) to facilitate the release of air, and to prevent any accumulation of sediment at the mouth of the tube.

As long as the slurry sank in the tube, more was poured in. Experience showed it was necessary to inspect the tubes every half hour, and fill them up as the mixture sank, until such time as it remained stationary.

Some difficulty was experienced in keeping the ingredients of the slurry, *i. e.*, one part cement to four parts of sand, homogeneously mixed together at the moment of pouring in, and finally it was found best to mix it dry, and pour it dry into the funnel while water was simultaneously poured in. It was intended to use a kankar-lime plug, finished up with cement on top, but the kankar-lime both from the local quarry at Kubah Chak and from Mansurwali, proved to be of such poor quality that recourse was had to cement and sand. For this 4 to 1 mixture hand-washed river sand was used, but the washing was afterwards abandoned, as the presence of a little clay was considered beneficial with cement, although injurious in the case of a lime mortar.

When all the springs in one bay had been closed, and the hydrostatic pressure thus increased, water very slowly but surely oozed through the pores of the plugs. This led to a final refinement of working details, *viz.*, the removing of the tube before the mixture had set hard, cutting out the top two inches in the form of a fox-tail, and handfilling with neat cement.

Cracks.

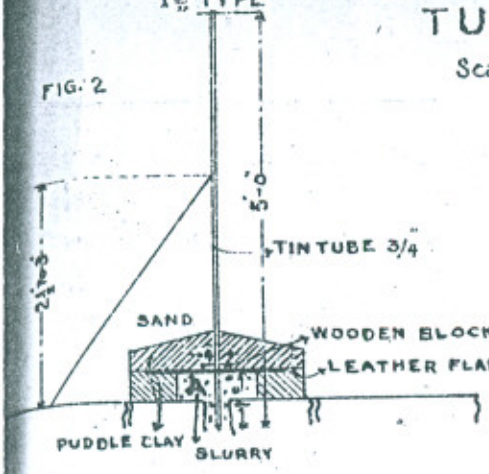
Fine cracks appeared, in some instances right in the middle of recently cement-repaired joints after stock-ramming some of the bays. These were at first attributed entirely to temperature changes, but it was subsequently observed that the cracks were much more numerous after completely staunching a bay than before, and this led to the conclusion that although probably temperature changes were the initial cause, they were assisted by hydrostatic pressure, and that the combination caused an increase in the number and extent of the cracks. These fresh cracks were chiefly found in the light-section between B and C lines of wells, but were not confined to that area, and it is probable that the increased hydrostatic pressure, in conjunction

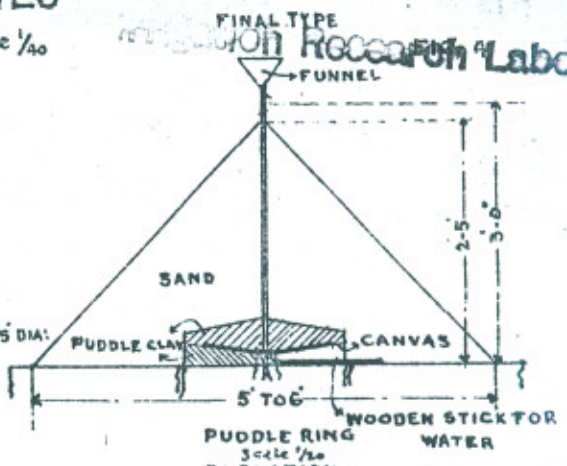
STOCK-RAMMING TUBES

Scale 1/40

Construction Research Laboratories

FIG. 2





Scale 1/20
ELEVATION

FIG. 5

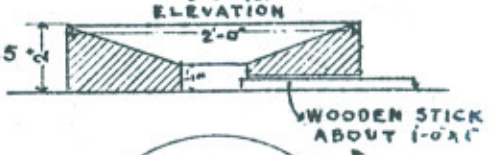


FIG. 3

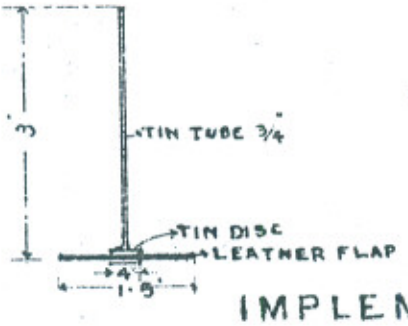
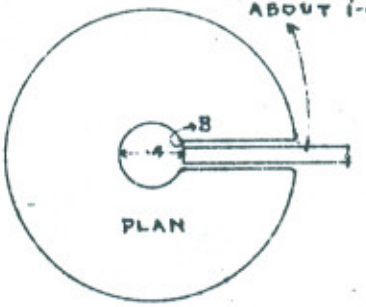


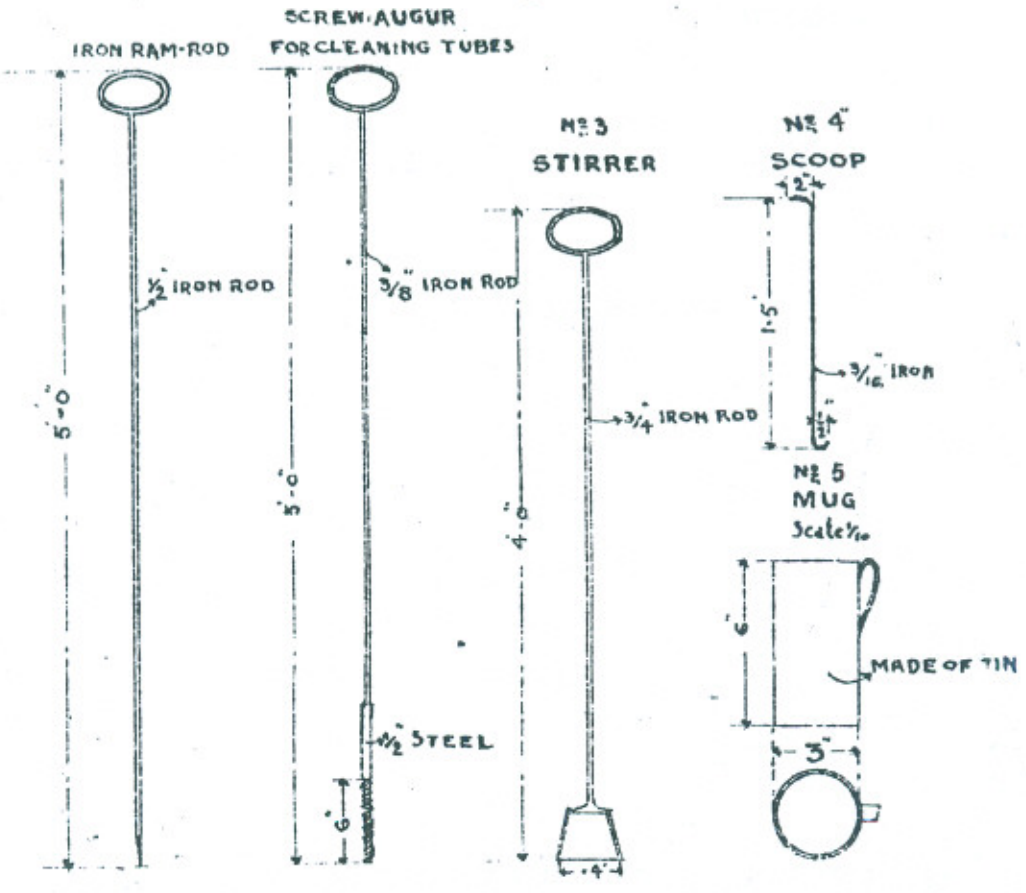
FIG. 6



IMPLEMENTS

Scale 1/20

FIG. 7



with the temperature stresses, also affected the permanent section of the weir. The cracks were very marked after the subsidence of a small flood which came down after the whole weir had been staunched, and at the same time several springs broke out in bays which had been perfectly dry before its occurrence.

PART II.

Desirability of Stock-Ramming.

The next question is the desirability or otherwise of maintaining the light section of this weir which corresponds to the grouted-pitching section of the Rasul and Khanki weirs, in a solid state, by stock-ramming.

The author after consideration of the following points is of the opinion that such staunching is not desirable, although this portion of the weir talus is thereby preserved against surface scour.

1. The staunching of the light section or grouted-pitching section is stated by Mr. C. H. Hutton, Chief Engineer, United Provinces, to have been one of the causes which contributed to the blowing up of Narora weir, owing to the increase of hydrostatic pressure caused thereby.

2. Mr. Nethersole, Inspector-General of Irrigation, considers that if the percolation line of the permanent section of such a weir, *i. e.*, A line to B line of wells, is designed so as to consume all head, and the pressure diagram is designed to have a flatter slope than the hydraulic gradient of the bed-soil, then all the head will be consumed before the end of the permanent section, *i. e.*, the downstream edge of B line of wells, is reached, and there will therefore be no pressure on the light section, and consequently no springs to stock-ram.

3. The staunching of this section seems to be contrary to what the author believes is the function of the section, *viz.*, to settle and fill up any scour, and be refilled with stone up to the designed level until it attains a permanent regime. This view is supported by the opinion of several experienced Punjab Irrigation Engineers whose names it is hardly necessary to mention.

4. Only superficial staunching is feasible, and there is a danger of hollow spaces, due to scour by retrogression or sand blowing, forming underneath this shell, and not being detected

until a large portion of the floor suddenly collapses. This actually happened on the side slopes of the head reach of the Upper Chenab Canal, where the banks were subjected to the ebb and flow of subsoil water.

5. It would appear that the original idea in weirs of this kind was not to staunch this portion, otherwise it is not understood why the bottom course of this section consists. in the case of Marala and Rasul weirs, of dry pitching-stone, the voids in which are large enough to allow a good surface flow, which must almost certainly result in the washing away of sand, and the formation of hollow spaces which would become dangerous if not followed by the settlement of the stone, which in the case of staunched masonry will not occur in a satisfactory manner.

PART III.

MISCELLANEOUS OBSERVATIONS.

Piping.

With regard to the question of piping—by which is meant the formation of hollow spaces underneath the pakka masonry owing to the "blowing" of sand—it may be remarked that the quantity of sand thus discharged might not appear excessive. One group of springs near the C line of wells with a head on the weir equal to crest-level, or 800·0—793·8=6·2 ft., gave one cubic foot of sand in twenty-four hours. This seems very little, but acting under a head up to shutter level, or 6·2 + 5·75 = say 12 feet it would probably give $\frac{1 + 12}{6{\cdot}2}$ = say 2 c ft. per twenty-four hours. This for the six months of short supply would give 6 × 30 × 2 = 360 cubic feet equivalent to a lead for a spring 270 feet long and 1·33 × 1·0 section, which would probably be sufficient to undermine the weir.

Mr. R. E. Purves, Chief Engineer, Punjab Irrigation, has stated that slight piping does not matter, *e.* g., there may be a velocity up to two feet per second, causing hollows six inches in diameter, without danger, but the writer ventures to suggest that even with slight piping, undermining is simply a matter of time.

In Appendices I A and I B calculations for Bligh's method of determining the hydraulic gradients are shown. These give a maximum gradient of 1 in 16. Appendices I C and

I D give the figures for Hutton's method on the assumption that the clay stratum is not more than thirty-four feet below the boulder stratum, to which the boring went down. These shew a maximum gradient of 1 in 10·6 ; and from these calculations—accepting the value of the hydraulic gradient of the river bed as 1 in 15, as given by Bligh for the same river forty miles lower down at Khanki—we see that considering safety against piping : —

By Bligh's Method.

Case i. Keeping the fore-apron impervious up to the C line of wells, gives a large margin of safety, *viz.*, $\frac{1}{22}$ as against $\frac{1}{18}$ considered safe by Bligh.

Case ii. Keeping the fore-apron impervious to B line only, there is a margin of safety of $\frac{1}{16}$ *cf.* $\frac{1}{15}$.

By Hutton's Method.

Case i. Gives $\frac{1}{10{\cdot}8}$ *cf.* $\frac{1}{15}$.

Case ii. Gives $\frac{1}{15{\cdot}3}$ *cf.* $\frac{1}{15}$.

Blowing up.

In some bays, with the shutters raised, an upstream water-level of 802·0 caused strings of air-bubbles to rise from a fine transverse crack in the weir crest upstream of the shutter line, and approximately along the upstream edge of the crest wall. There thus appears to be a possibility—even if a remote one—of water forcing its way between the rear-apron and the crest wall in sufficient quantity to create direct hydrostatic pressure at that point, equal to the head of water, which may be at R. L. 805·75. This would cause a pressure on the underside of the fore-apron at its junction with the crest wall, equal to 805·75—795·67 or say 10·1 feet. Deduct loss of head by frictional resistance (accepting Bligh's value of 1 in 15 for the hydraulic-gradient) as follows :—(800—788·5 + 8 + 795·67—788·5) ÷ 15 equals 1·8 feet. Thus 10·1—1·8 equals 8·3 feet, which is balanced by four feet of masonry of specific gravity 2·0, *i. e.*, eight feet equivalent head. The unbalanced head of 0·3 ft. seems to be risky unless the tension in the mortar joints is considered to give a sufficiently large factor of safety.

On opening up portions of the fore-apron to a depth of eighteen inches, nearly the whole of the exposed area was seen to

be interspersed with very fine sand. The source of entry of this sand could not be definitely traced, but its presence may eventually show that the blowing up of the top layer of the fore-apron is not an impossibility.

Appendix II A shows the hydrostatic pressure at various points, assuming that the whole weir between A line and B line is impervious.

Appendix II B shows that in bay No. 7, where water is found to be flowing freely beneath the light section, there is an unbalanced head of five feet, and safety at this point must thus depend upon the tension in the joints.

Appendix II C shows that if this 'flow' only starts from the downstream side of the crest wall, the unbalanced pressure is from 2 to 4·5 feet.

Appendix II D shows that if, as seems most probable, this 'flow' starts from the downstream edge of B line of wells, owing to the loose dry-stone foundation, then there is no unbalanced pressure.

Appendix II E shows that in Bay No. 2 the flow from a spring backed up to such a height as to cause a pressure of 3·9 feet, partly balanced by 3·5 feet, gave 0·4 feet unbalanced head, which depended upon the tension in the joints. Whether the pressure of 3·9 feet was produced by head from above the weir, or from saturated sand deposits on the talus, is uncertain.

Although the author has not come to any definite conclusion as to the point up to which the sandy river bed acts as a head-destroyer, and thus affects the actual hydraulic gradient, he leans to the opinion that the 'flow' starts downstream of the B line of wells, and that thus, according to the calculations in Appendix II D, the light section floor up to C line of wells is just stable; but the fact that the slurry in stock-ramming-tubes stood at 1·5 to 2 ft. above the floor top level, or 3 to 3·5 ft. above the floor bottom level, and that this pressure was only balanced by 1·75 ft. of masonry of specific gravity=2·0, or 3·5 effective head, shows that the light section is liable to be in a state of unstable equilibrium, and that the staunching of it, while not materially flattening the hydraulic gradient, owing to the 'flow' in the dry stone approximating to ordinary 'surface-flow,' causes such a pressure-head to act so as to endanger its safety by 'blowing up'.

Conclusion.

It seems to the author that these questions, which have developed out of a simple matter of weir maintenance, are of great importance, and affect the stability as well as cost of construction and maintenance of weirs, and that their discussion in an open-minded manner may enable the younger generation of Irrigation Engineers to profit by the exchange of views, which, it is hoped that this paper will promote, and after hearing the opinions of some of the more experienced men of the Department, apply the accumulated results to weir designs of the future.

APPENDIX I. A.

HYDRAULIC GRADIENT (BAYS NOS. 7 AND 8).

Bligh's method. A line to B line of wells.

HORIZONTALLY.

Rear-apron slope	...	...	33'
Weir crest ...	...	...	14'
Fore-apron slope	...	...	46·5' = 93·5'

VERTICALLY.

A line of wells 26·0+26·0—(4·5—$\frac{5}{6}$) =		...	48·8'
Crest wall (11·5—4·5)+7·0 =		...	14'
B line of wells 18·6+(18·6+$\frac{8}{12}$—4·0) =		...	33·8' = 96·6'
	Total	...	190·1'

Taking the maximum head when the shutters are up, and the level of the talus (793·8) as L. W. L.

Head equals 805·75 – 793·8 = say 12·0 ft.

Therefore the hydraulic gradient equals 12 in 190 or 1 in 16.

APPENDIX I. B.

If the 'light-section' is included, *i. e.*, A line to C line of wells—

Deduct from	...	...	190'
Vertically ...	...	...	—3·25'
Add horizontally	...	...	46·5'
Add vertically (16—3·25)+16·0	...	...	28·75' = 262

The hydraulic gradient then becomes 12 in 262 or 1 in 22.

APPENDIX I. C.

HYDRAULIC GRADIENT (BAYS NOS. 7 AND 8).

Hutton's method. A line to B line of wells.

HORIZONTALLY.

Rear-apron slope	33·0	
Weir crest	14·0	
Fore-apron slope	46·5	= 93·5

VERTICALLY.

Assuming the rectangular wells and intermediate piles to form an impervious screen.

Then, if F equals the equivalent floor value.

W „ the (axial) width of obstructing screen.

A „ Area (per unit length) of soil from floor level to impervious stratum.

P „ Area (per unit length) of pervious or unobstructed portion.

F „ $\frac{W\,A}{P}$

For A line of wells F_1 equals $\frac{8{\cdot}0\times(794{\cdot}5-730{\cdot}0)}{(766{\cdot}5-730{\cdot}0)}$ = 14·1

„ Crest wall F_2 „ $\frac{8{\cdot}0\times(795\,5-730{\cdot}0)}{(788{\cdot}5-730{\cdot}0)}$ = 9·0

„ B line of wells F_3 „ $\frac{8\,0\times(792{\cdot}9-730{\cdot}0)}{(777{\cdot}8-730{\cdot}0)}$ = 10·5 = 33·6

Total 127·1

Therefore the hydraulic gradient equals 12 in 127·1 = 1 in 10·6

APPENDIX I. D.

IF THE 'LIGHT-SECTION' IS INCLUDED.—

A line to C line of wells.

HORIZONTALLY :—	to	93·5'	
	add	46·5'	= 140·0'

VERTICALLY.

A line, as before	F_1 equals	14·1'	
Crest wall, as before	F_2 „	9·0'	
B line of wells	„ F_3 „	10·5'	
C line of wells	„ F_4 „ $\frac{8{\cdot}0\,(790{\cdot}6-730{\cdot}0}{(777{\cdot}8-730{\cdot}0)}$	10·2'	= 43·8'
	Total ...		183·8'

Therefore the hydraulic gradient equals 12 in 183·8 = 1 in 15·3.

NOTE.—R. L. of impervious stratum assumed to be 730·0.

APPENDIX II.

Hydrostatic Pressure.

Case.	Distance from upstream edge of A line of wells.	Description.	Upward pressure in feet of water.	Balancing pressure. Thickness.	Specific gravity.	Equivalent head.	Difference in favour of safety.
		II A.					
Accepting Bligh's method and considering the permanent section of the weir.	44	Junction of crest wall and fore-apron.	$(805\cdot75-795\cdot67)-\left(\frac{4+50\cdot7+14}{15}\right)$ $=10\cdot1-7\cdot25=2\cdot85$ ...	4	2	8	+ 5·15
As from A line to B line of wells.	85·5	Upstream edge of B line.	$(805\cdot75-792\cdot9)$ $-\left(\frac{33+14+38\cdot5+50\cdot7+14}{15}\right)$ ...	4	2	8	+ 5·20
		II B.					
Bay No. 7 where there appears to be full hydrostatic pressure.	44	Junction of crest wall and fore-apron.	$805\cdot75-795\cdot67=10\cdot1$ ...	4	2	8	−2·1
Unretarded by frictional resistance on the downstream side of crest.	85·5	Upstream edge of B line.	$805\cdot75-792\cdot9=$ say 13 ...	4	2	8	−5·0

		II C.						
Assuming the 'flow' to start from downstream of crest wall.	93·5	Downstream edge of B line.	$(805{\cdot}75-793{\cdot}15)-\left\{\frac{44+50{\cdot}7+14}{15}\right\}$ $=12{\cdot}6-7{\cdot}25=5{\cdot}35$	...	1·75	2	3·5	−1·85
	132	Upstream edge of C line.	$805{\cdot}75-790{\cdot}6$ or $15{\cdot}15-\left\{\frac{44+50{\cdot}7+14}{15}\right\}$ $=15{\cdot}15-7{\cdot}25=7{\cdot}9$	...	1·75	2	3·5	−4·4
		II D.						
Assuming that the 'flow' takes place from the downstream edge of B line of wells.	93·5	Downstream of B line.	$12{\cdot}6-12{\cdot}8=-0{\cdot}2$	..	1·75	2	3·5	+3·7
	132	Upstream of C line.	$15{\cdot}15-\frac{192}{15}=2{\cdot}35$	...	1·75	2	3·5	+1·15
		II E.						
In bay No. 2 the water in one spring headed up to R. L. 796·0. This would give pressure on the bottom of the floor near C line of wells.	132	Upstream of C line	$796{\cdot}0-792{\cdot}1=3{\cdot}9$	..	1·75	2	3·5	−0·4

DISCUSSION.

MR. COLYER as an introduction to his paper read out the first and last paragraphs in order to emphasize the object in view, and promised an errata-silp altering some of the calculations in detail, but not affecting the conclusions. He suggested, as a solution of the problem, the advisability of putting in 'blow-holes' in the grouted-pitching or light-section, if it was thought necessary to grout it for protection against face-scour. He then drew attention to Mr. Hutton's theory, and mentioned that on looking at his plates (Hutton on the Narora Wier, Simla Conference 1913), he thought that the sheet-piling had more effect than his method of calculation gave it credit for.

The author emphasized the vast difference of opinion upon the correct method of calculating the hydraulic gradient, as instanced in Bligh's and Hutton's methods, and remarked that if Mr. Brownlie's statement was proved, that sand was more porous in a horizontal than in a vertical direction. It would entirely upset present ideas on the hydraulic gradient problem.

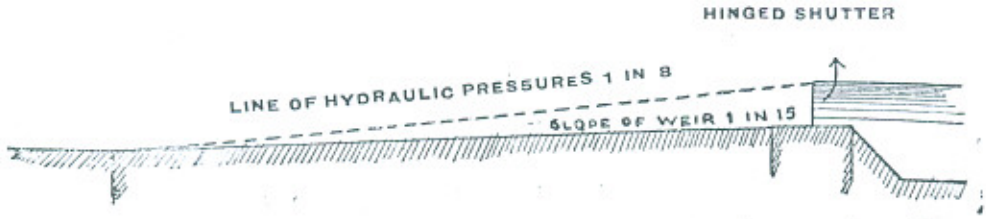
He noted with satisfaction that the views expressed in his paper against stock-ramming the light section of a weir, had been subsequently endorsed, in the case of Marala Weir, by the Chief Engineer who, after inspecting the works at site, had ordered that this portion should not be staunched.

Mr. SCHÖNEMANN said he did not know what ground there was for the assumption that the natural hydraulic gradient through the bed-sand of the River Chenab at Khanki, or at Marala was 1 in 15 ; but granting that to be the case, he did not see why sand-blowing should occur ; seeing that the glacis of the Marala Weir was also sloped at 1 in 15.

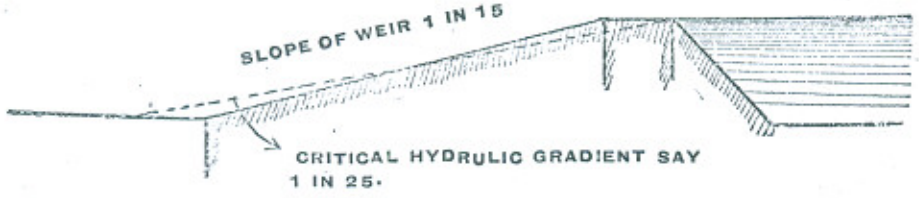


With the hydraulic gradient lying within the material of the weir, and not flatter than the slope of its glacis it was difficult to see how the excess of pressure-head, which caused sand-blowing, could occur above the surface of the masonry.

In his opinion the sand-blowing was more likely to be due to the use of hinged shutters on the weir crest.



The drop of the weir from crest to talus, being about six feet, the hinged shutters, six feet high, when in use, had the effect of doubling the steepness of the hydraulic gradient, and of bringing the line of hydraulic pressures above the surface of the glacis. This would account for the sand-blowing. (Here Mr. Colyer said that the shutters were not in use at the time of the sand-blowing; whereupon Mr. Schönemann remarked that, if that were the case, the sand-blowing could only be accounted for on the supposition that the "critical" hydraulic gradient for the Marala river sand must be considerably flatter than 1 in 15, thus) :—



RAI BAHADUR BAIJ NATH said he had had some experience of stock-ramming and could not agree with the Author's convictions that it was inadvisable.

MR. COLYER replying to Mr. Schönemann said that, in taking 1 in 15 as the value of the hydraulic gradient for Chenab River sand, he had followed Bligh, and the records of experiments at Marala during construction, which showed 1 in 15 to be correct. The appearance of springs could not be laid at the door of the weir shutters, as although these were up for repairs at the time, they had no effect, as the weir crest was dry, and the whole cold weather supply was passing through the undersluices.

With regard to the sand-blowing, it was not a matter of speculation, as the author had actually measured the amount of

sand blown by one group of springs, and it had amounted to one cubic foot of sand in twenty-four hours

In reply to Rai Bahadur Baij Nath, he said that his reasons for not advocating the stock-ramming of the light-section, was that it increased the hydrostatic pressure, not only on that section, but also on the permanent section, as was instanced by the subsequent appearance of cracks in Marala weir, in places which had previously stood the temperature stresses intact.

THE CHAIRMAN (Mr. R. E. Purves) in summing up, regretted that the discussion on the interesting subject of this paper had to be hurried through the last few minutes at the close of the session, and that there had not been sufficient time to do it justice. So far as the discussion had gone, it shewed that their present knowledge of the hydraulic gradient in canal works was in its infancy, and that the causes bringing it about were somewhat obscure. The authorities quoted did not agree, and did not appear to be themselves quite certain on the subject. They merely quoted some examples, but the examples varied very considerably and were insufficient in number. The strength of the springs and the blowing of sand depended largely upon the character of the sub-soil. Experience in the Punjab at any rate went to show that, in some cases hydraulic gradients of 1 in 10 were quite safe and did not blow sand, while, on the other hand, 1 in 16 and 1 in 18 would in certain localities result in sand-flowing. Their knowledge was incomplete, and they must wait for more examples to enable them to establish suitable laws, which would be generally applicable with the necessary modification for the special circumstances of each locality.

Before closing the session the Chairman said he would like to give expression to their thanks to the able writers of the papers, which had been discussed at the meetings, and for the trouble they had taken to bring forward the papers.

He felt sure that he was voicing the general feelings of the meeting when he said that the papers and the discussion thereon, had been of much benefit to them all. The subjects taken up had not only been interesting but were of much importance to them professionally.