PAPER No. 227.

A STUDY OF RIVER CONDITIONS AT KHANKI HEADWORKS BY MEANS OF A MODEL AND AN INVESTIGATION OF METHODS FOR OBTAINING UNIFORM DISTRIBUTION OF FLOW AND MINIMUM SILT ENTRY INTO THE CANAL

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Introduction.

Khanki Headworks as originally constructed in 1892 consisted of a weir accross the river, undersluices in the weir and a head regulator in the canal. The bell-shaped guide banks with a length of 5,500 feet upstream of the weir and 1200 feet downstream of the weir were the only training works considered necessary at the time of the construction of the headworks. With these training works alone, the approach to the weir was found to be much obstructed by the growth of islands. With a view to training the river into a uniform channel above the weir a series of training spurs on the right bank of the River Chenab were constructed five years after the completion of the Headworks. The presence of these spurs deflected the course of the river to the left and caused heavy silting up of the canal. In fact, whenever the river flowed along the left bank the canal became heavily silted up. The conditions at Khanki continued to be unsatisfactory and in 1933 it was decided to re-condition certain bays of the weir.

Mr. Nicholson's proposals for remodelling were based on the following points :—

(1) *To draw a reasonable portion of the flood discharge of the river away from the canal regulator, while maintaining the left channel with certainty.* As the right channel took off at an angle from the main river it would have a tendency to draw a greater proportion of the silt.

(2) *To obtain the curvature of flow in the river upstream of the undersluices for securing conditions of minimum silt entry into the canal.*

In order to achieve these two conditions, bays 4 and 8 of the weir were converted into undersluices with their crest levels considerably below that of the other weir bays. The re-conditioning was completed in 1935. Conditions show little or no improvement in the subsequent three years. The right channel has over-developed due to the working of bay 8 while the curvature of flow, to obtain which bay 4 was constructed, has not materialized. The regulation programme followed after the re-conditioning of the weir was to pass two-thirds of the discharge down the right channel and one-third down the left channel in the case of normal monsoon discharges, while in the case of flood discharges the reverse proportion was adopted. As floods were rare this programme led to the over-development of the right channel while the left channel began to silt up. Also, due to the formation of *belas* in front of bay 4 the straight flow towards this bay stopped altogether.

The two essential requirements at each canal headworks are :—

1. *To pass the flood discharge as uniformly as possible over the weir.*

2. *And to allow the minimum quantity of harmful silt to enter the canal.*

From the above points of view the conditions at Khanki Headworks in the spring of 1938 appeared to be far from satisfactory. The right channel was over-developed while the discharging capacity of the right half of the weir was much less than that of the left and it was feared that a high flood might cause damage to one or more of the bays on the right. Secondly, if this regulation programme was continued, what would happen to the left channel and to bay 4?

In order to study these and many other similar problems it was decided to make a detailed examination of the river conditions on a model of Khanki Headworks.

Experiments were carried out on a large scale at the River Research Station at Malikpur.

Construction of the Model.

A study of the river survey plans showed that it was necessary to represent in the model the stretch of the river between Alexandra Bridge and the weir line. At Alexandra Bridge the river flowed in one channel and the gauges were read and recorded regularly.

The horizontal scale adopted was 1/200. The vertical scale was derived from Lacey by Bose and a value of 1/34 for the same grade of sand as that on the prototype was obtained. As the sand used in the model was slightly coarser than that in the prototype a scale of 1/30 was finally adopted. A complete model to the above vertical and

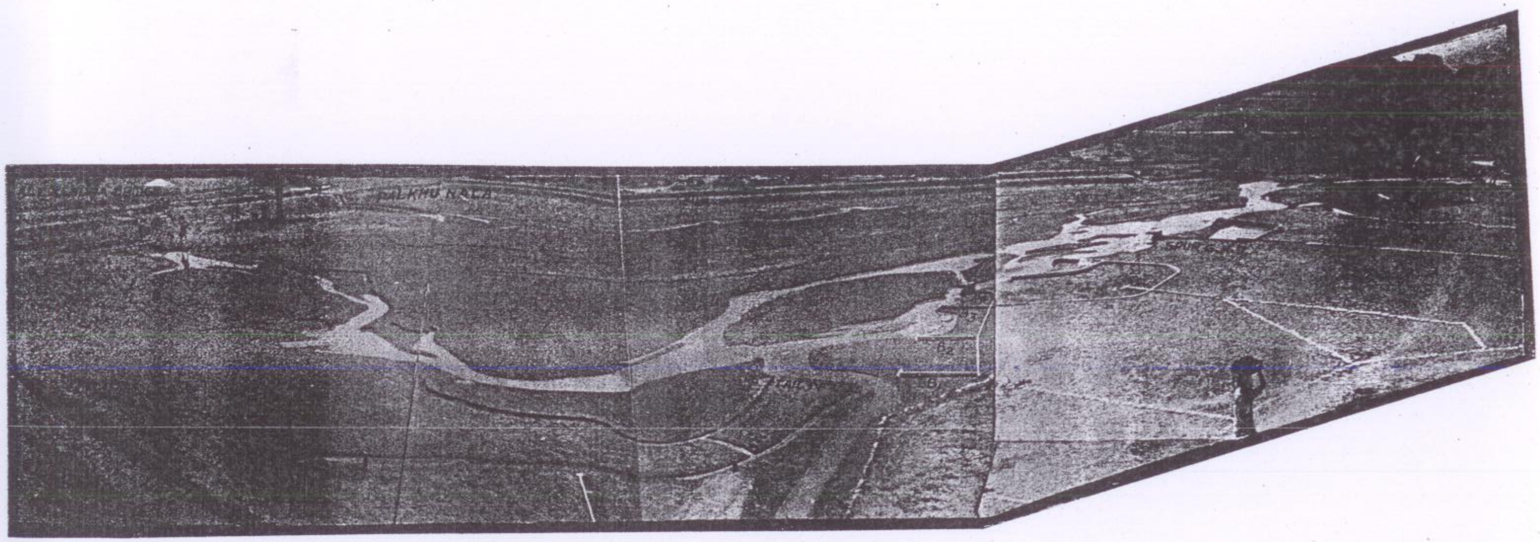


Photo No. 1. View of the Complete Model.

horizontal scales was constructed and is shown in Photo No. 1. At the downstream end of the model the weir was divided into two portions by means of a partition wall built in continuation of the bund at bay 5 so that the river discharge and the silt charge in each channel (bays 1 to 4 and bays 5 to 8) could be determined accurately. The discharge was measured by allowing the water to pass over sharp-crested weirs and the quantity of silt was determined by collecting it in pits below. A similar arrangement was provided downstream of the canal regulator.

Verification Runs.

The following scale ratios were fixed by Dr. N. K. Bose :—

Discharge scale 1/32,860.

Silt to be dropped on the model=54 cubic ft. in the course of a year.

For determining the time scale the model was run for three different ratios :—

1. $1\frac{1}{2}$ hours on the model =1 month on the prototype.
2. 3 hours on the model =1 month on the prototype.
3. $4\frac{1}{2}$ hours on the model =1 month on the prototype.

The last ratio was found to give very satisfactory results and was adopted.

For the vertification runs the model was moulded to the conditions of 1934 and run for a period equivalent to one year. At the end of the run, a survey of the bed was made and was compared with a survey of the prototype made in November, 1935. The water levels at the gauge points corresponding to those on the prototype were recorded. The agreement between the prototype and the equivalent model values was satisfactory.

In the second verification test the bed was moulded according to the survey of 1937 and run with the discharge equivalent to those experienced on the prototype in 1938.

To start with, a small quantity of water was let in at the Alexandra Bridge to fill the model, the gates of the undersluices and the canal regulator all being kept down. After about an hour when the sand bed was saturated and the water level headed up against the gates to R.L. 732 the regulator gates were raised to run the canal, and the undersluice gates were lifted to pass the extra supply below the weir. A mean of ten days' discharges was taken. Similarly a mean of the corresponding gauges was also calculated for the same period. The model was run with one average discharge for a period of $1\frac{1}{2}$ hours which is equivalent to ten days on the prototype. At the end of this period the next average discharge was run and the experiment was continued in this way up to the end of September.

The following observations were made :—

1. Gauges at all the points on the weir as well as upstream and downstream of the weir were recorded.

2. The gate openings of the undersluiced bays were observed.

3. The discharges of the two channels were determined separately.

4. The quantity of silt carried into the right and left channels and into the canal was determined.

5. The directions of flow in the case of important runs were also noted.

6. The velocity observations for flood discharges were made.

As a result of the analysis of the data and its comparison with the observations made in 1938 in the prototype it is shown that the current directions, the velocity observations and the gauge readings at spur points agree closely. For example, the velocity on August 11, in the model and prototype were similar, as shown below :—

	Prototype. Actual velocity in feet per second.	Model. Equivalent velocity in feet per second.
Left Undersluices ..	13·1 12·9	12·9 13·5
Right Undersluices ..	12·0 10·0	11·7 9·4

The following gives an account of the tests that were made after proving the model.

Determination of the Effect of the Continuation of the Present Method of Regulation on the Bela Formation.

It was desired to run the river for a further period equivalent to one year to ascertain the positions and sizes of the *belas* at the end of 1939, if the present method of regulation was continued. The conditions of flow in 1937 were selected to represent those in 1939 as usually a year of comparatively high rivers like 1938 is preceded or followed by a year of low rivers such as 1937. The six observations in the verification runs were also made in this test and at the end of the run a detailed survey

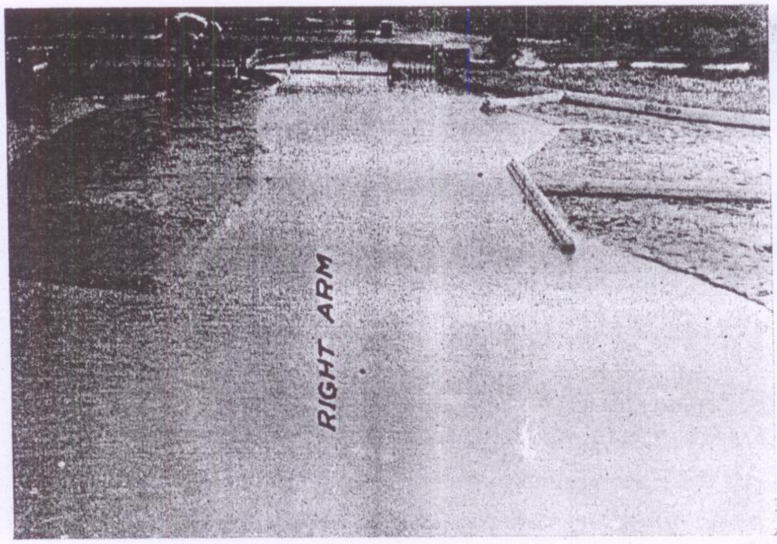


Photo No. 2.

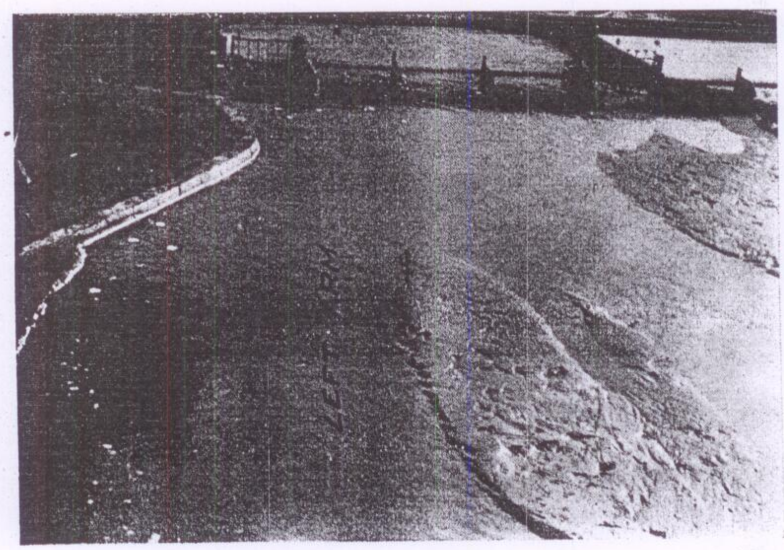


Photo No. 3.

of the bed was taken. Observations for scour at important points were also made. From an examination of the data the following indications were obtained :—

No. 1. Two small *belas* between spurs B 2 and B 3 disappeared and an embayment formed along which there was a strong current which severely attacked the nose of spur B 3.

No. 2. The two *belas* in front of the embayment between spurs I Lower Arm and G H Upper Arm formed into a bigger *bela*, with distinct channels on the right and left of it.

No. 3. The main stream bifurcated at a point higher up than the nose of the central *bela*.

No. 4. The right channel broadened out and the subsidiary *belas* in this channel disappeared. The right face of the main *bela* was eroded and straightened out. The nose of spur A was carried away (Photo No. 2).

No. 5. The creek close to the main *bela* which used to flow to bay 4 from the left channel became choked. The whole of the water in the left channel flowed along the left bank to the left undersluices and then parallel to the weir to bay 4 (Photo No. 3).

No. 6. There was considerable erosion of the left bank between the New Palkhu Spur and the Left Protection Bund. Deep scour holes formed in front of the right undersluices, bay 7, right half of bay 3, right half of bay 2 and right corner of bay 1 while bay 5 silted up.

In order to show conditions in 1940, if the present method of regulation was continued, the model was run for a further period equivalent to one year during which the conditions of flow in 1938 (a year of high rivers) were adopted to represent the probable conditions of flow of 1940 for reasons already given. Flood discharges of 2,64,000 cusecs and 2,40,000 cusecs which occurred in 1938, were also run. The current direction at important places and velocity observations of flood discharges above one lakh cusecs were also taken. At the end of the run the river survey of the bed was taken and is shown in Plate I. The following important indications regarding the probable conditions of 1940 were obtained :—

1. By the end of June the right channel was considerably overdeveloped. The point of bifurcation of the main stream shifted to a place just downstream of spur G H Lower Arm. Looking downstream from spur B 4 the main river flowed along the line of spurs right up to the right undersluices. Just upstream of the nose of central *bela* a small part of the discharge entered the left channel. The river in the right

channel below spur E flowed along the guide bank and point A. At the upstream nose of the former, heavy action took place. The central *bela* extended towards the left both at the nose and at the tail end. The water in the left channel flowed in a small creek along the Palkhu spur and then along the embayment between the Palkhu spur and the Left Guide Bank.

2. In the flood of over 2,50,000 cusecs the current in the right channel became very strong. Most of the *bela* was overtopped. The proportion of discharges in two channels was three in the right to one in the left. The silt carried down in the right channel was considerably greater than that in the left.

3. As the river dropped in September, it was found that the supply in the left channel was not sufficient to feed the canal due to the formation of fresh *belas* in this channel which almost completely blocked it (Photo No. 4). In the right channel, however, all the subsidiary *belas* disappeared.

An Examination of Different Methods of Improving the River Conditions.

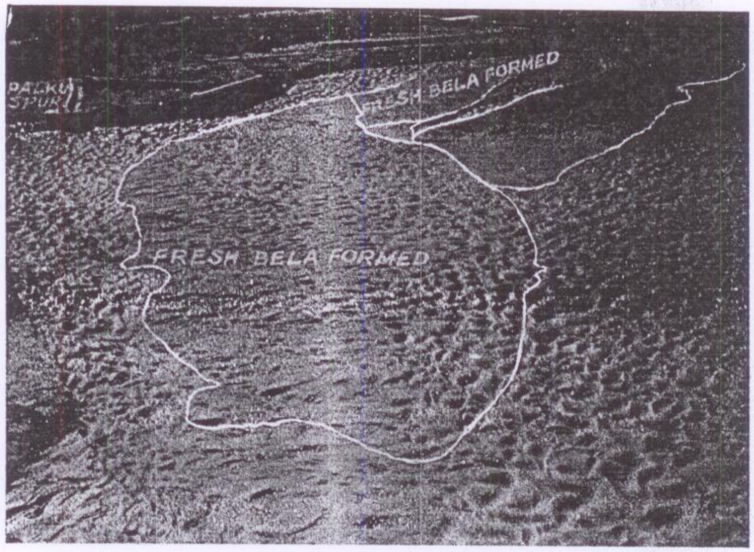
Testing the effect of making a leading cut to Bay 4.

From an examination of Plate I it will be seen that bay 4 is connected to the left channel for the passage of surplus water downstream of the weir by a bund at the groyne between bays 4 and 5. The existence of the *belas* in front of bay 4 makes direct approach to bay 4 impossible. This bay has been designed to pass a discharge of 1,25,000 cusecs while due to the unfavourable approach, it can hardly pass more than 50 to 60 thousand cusecs. On the other hand the discharge in the right channel in high flood may be considerably more than what can be passed with safety through bays 5, 6, 7 and 8. It was, therefore, decided to investigate the possibilities of obtaining uniform distribution by connecting bay 4 to the right side.

A cut was made in the main *bela*, from a point opposite spur A to bay 4. The cut was 60 feet wide, 12 feet deep and 2200 feet long. An attempt was made to develop the cut in the winter freshets. The model was moulded to the river survey of 1938 and a discharge of 10,000 cusecs was run to begin with, which was increased to 54,000 cusecs to represent freshet discharges of January. The following pond levels were maintained :—

Right pond at R. L. 730.

Left pond at R. L. 729.



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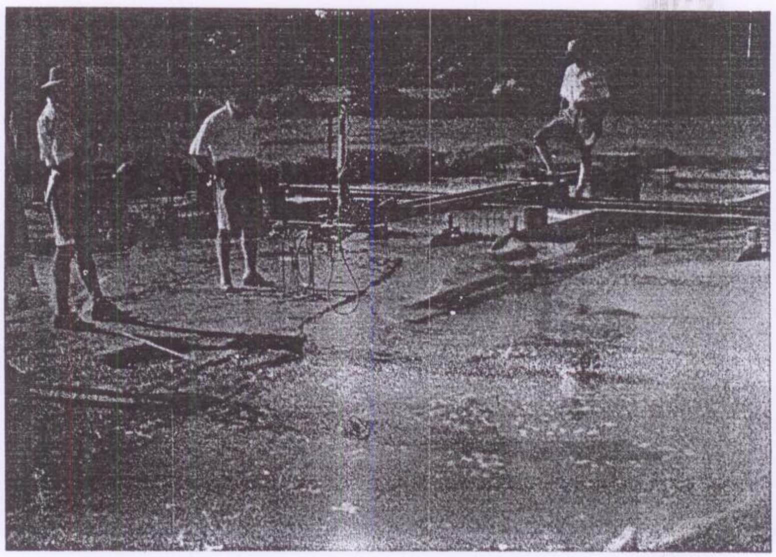

Photo No. 5.

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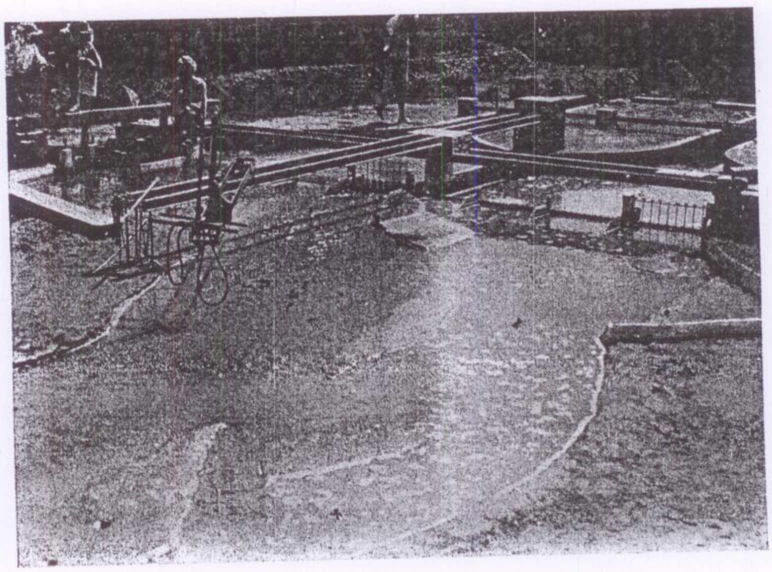

Photo No. 6

The Punjab Engineering Congress, 1939.

The central undersluices were opened as much as possible. In a period equivalent to two days the cut widened to 150 ft. The next freshet discharges to be run were 39,000 cusecs and 76,000 cusecs with pond levels at R. Ls. 732 and 730·5 on the right and left respectively, as a result of which the cut developed to the extent shown in Photo No. 5 with a maximum bed width of 450 feet. This was increased to 850 ft. when the April discharges were run. The model was also run with the discharges of May, June, July and August.

In the beginning of June, it was noticed that the whole of the *bela* on the right side of the cut was washed away and only the bund which divided the weir into two portions remained. The conditions of flow at this stage (see Photo No. 6) were interesting. There was a channel to bay 8 ; a second to bay 4 and a third one on the left to the left undersluices. The bifurcation of the stream towards the right and the central undersluices took place opposite spur A. The action at the nose of the main *bela* was severe. By the middle of June the bund at Bay 5 was also washed away thus connecting the two channels. It was noticed that about 80 per cent. of the supply passed through the right channel and the approach of the river from bays 3 to 8 was practically straight in the case of high flood discharges. When the river fell in September it was found that no water passed down the left channel with a discharge up to 20,000 cusecs and the canal supply came from the right channel.

In the next test the model was run with supplies corresponding to a low discharge year. It was found that the cut developed fully during the June discharges and the final conditions were almost the same as those obtained in the previous test.

It has been shown from these tests that when the cut develops, the bund which divides the weir into two is washed away. The right edge of the main *bela* is further eroded and the approach of the river to bays 3 and 4 straightens out. Severe action develops at the nose of groyne 4. If the right edge of the *bela* is further eroded it is probable that in time of flood the central current may take a course straight to Bay 1 or to the left undersluices. The bed of the river in front of Bay 8 is slightly raised and the channel to this bay decreases in size. The discharge in the left channel drops almost to nothing. In low rivers the canal is fed from the right, causing parallel flow along the weir from bay 6 to the left undersluices.

If this method is adopted on the prototype the groynes of bay 4 will have to be dismantled or strengthened.

Determination of the optimum discharge in the left channel for satisfactory silt conditions in the canal.

The river bed was laid to the survey of 1937-38 and the discharge in the river was gradually raised to 85,000 cusecs. The proportion of discharges in the two arms was adjusted by developing the right channel till the following distribution was attained :—

Left channel 20,000 cusecs.

Right Channel 65,000 cusecs.

The canal was then opened. The left pond was kept at R. L. 733·0 and the right at R. L. 729·4. Silt was now fed into the river and the model was run for six hours. After stopping the model the quantities of silt in the two halves of the river downstream of the weir and the canal were measured. Similarly the following proportions of discharges in the two arms were next examined :—

		Left.	Right.
Discharge	..	30,000 cusecs.	55,000 cusecs.
,,	..	40,000 ,,	45,000 ,,
,,	..	50,000 ,,	35,000 ,,
,,	..	57,000 ,,	28,000 ,,

The quantity of silt entering the canal has been plotted against the discharge in the left arm (Plate II). An examination of this curve shows that up to a discharge of about 40,000 cusecs the quantity of silt deposited in the canal is proportional to the discharge in the left channel, but with discharges above this figure the quantity of silt increases very considerably, as is shown by the curve. The most favourable discharges in the left channel for optimum silt in the canal are those below 40,000 cusecs.

Determination of the optimum water surface slope in the left channel for satisfactory silt conditions.

Two tests were carried out. In the first test a discharge of 85,000 cusecs was run in the river and the effect of different slopes in the water surface between the Palkhu Spur and gauge No. 13, *i.e.*, between 1/1000 to 1/5000) was studied. In the second test the discharge was reduced to 40,000 cusecs and slopes flatter than 1/7200 were examined. Plate III shows their results.

It will be seen from an examination of these curves that if the slope is steeper than 1/4500 the quantity of silt entering the canal increases considerably.

In order to eliminate harmful silt entry into the canal a slope not steeper than 1/5000 should be maintained.

It must, however, be made clear that these tests as well as the previous one are only comparative as the figures obtained in the model bear no relation to those on the actual. However, very important indications are obtained from this test.

Determination of the quantity of silt entering the canal if the canal was fed from the right channel.

In order to determine the quantity of silt entering the canal if fed from the right the river was modelled to the 1937-38 river survey and a cut was made in the *bela*. The left channel was closed at the nose of the main *bela* by a bund the top level of which was kept the same as the level of the *bela*. The model was run and the cut was developed as before. In 20 minutes the cut took a discharge of 40,000 cusecs.

The discharge in the river was slowly raised to 85,000 cusecs and the canal was opened. The bund closing the left arm was not overtopped so that the canal was fed from the water coming through the cut to the central undersluices. Silt was fed as in the test for determining the optimum discharge in the left channel.

Comparison of the quantity of silt entering the canal when the canal is fed from the left and when it is fed from the right channel.

After completing the previous test, a cut was made in the bund across the left arm so that the left undersluices could be fed from the left side. The model was run with 85,000 cusecs and silt was fed as before. At the end of the run the silt in the canal was 0·07 cubic feet only. An important conclusion obtained from the above tests is that by feeding the canal from the right more silt goes into the canal than that by the straight flow from the left channel.

Dismantling the bund at bay 5 and connecting bay 4 to the right channel by making a bund at bay 3.

As the downstream end of the central *bela* extended to the groynes of bays 4 and 5, a passage equivalent to about 50 feet width was made between bay 4 and the *bela*. A discharge equivalent to 25,000 cusecs was run and the canal was opened. The following pond levels were maintained :—

Right	..	R. L. 732·5
Centre	..	R. L. 731·0
Left	..	R. L. 731·5

The whole of the discharge in the right arm was passed through bay 4 and the originally narrow passage was widened to 258 ft. Parallel flow started from groyne 6 to groyne 1. At groyne 4 the action was severe. Smooth flow took place along the *bela* resulting in no erosion with a discharge of 25,000 cusecs. The portion of the *bela* in front of bay 5 was attacked and consequently was widened out as the discharge increased. On the left side, bays 1 to 3 showed signs of silting up. Downstream of the nose of the central *bela* the left stream divided itself into two, one along the Palkhu Spur and the guide bank and the other along the left edge of the central *bela*. That along the left guide bank entered the regulator. The other flowed along the *bela* to bay 1, curving along the upstream divide wall. This is indicated clearly in Photo No. 7.

Next, a discharge of 76,000 cusecs was let in. Half an hour after running this discharge a portion of the bund from the *bela* to groyne 3 gave way. (Photo No. 8.)

The discharge was then increased to 1,00,000 cusecs. Shutters in bays 6, 2 and 1 were dropped to pass the surplus above what could be taken by the central undersluices. The downstream end of the *bela* was not much eroded with this discharge. There was however some erosion of the right edge of the *bela* in front of Spur A. Parallel flow still persisted from bay 7 to bay 4. One important change brought about with this increased discharge was that the channel first approached bay 6 and then took a course to bay 4.

The discharge was next raised to 1,50,000 cusecs and this breached the bund. The path of flow was however similar to that observed with 1,00,000 cusecs discharge. The distribution of discharges for the two halves of the weir was as follows :—

Right	..	89,000 cusecs.
Left	..	40,000 cusecs.

Swirls of appreciable magnitude formed at groyne 5.

In order to study the distribution of supply during high floods, discharges of 2,64,000 cusecs and 4,00,000 cusecs were run. The *bela* was overtopped in the case of 2,64,000 cusecs the water spilling over from right to left. Bay 4 under these conditions did not pass the discharge due to bad curvature of flow. With a discharge of 4,00,000 cusecs the whole of the *bela* as well as the bund was overtopped and the flow was more or less evenly distributed. On the whole the conditions in the case of this flood were similar to that already stated.

Conclusions.—Running the model for a period equivalent to one year showed that the section of the river in front of bays 5 and 6 does not

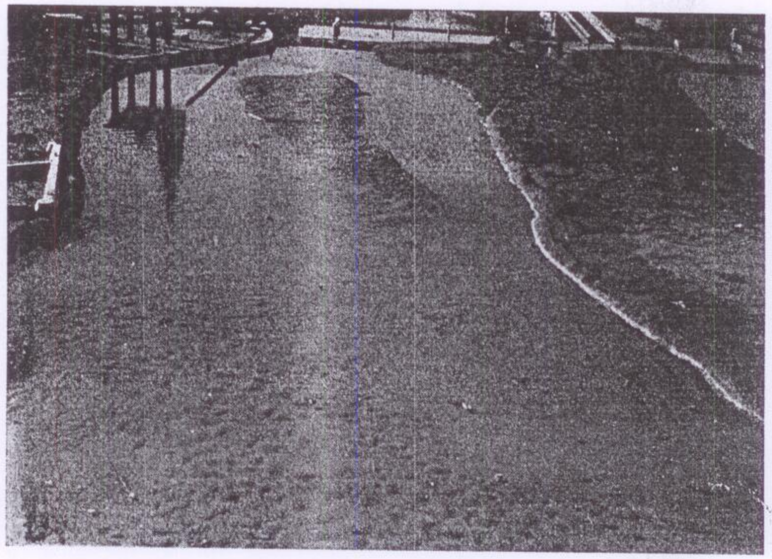

Photo No. 7. Currents in left arm of the River.

Photo No. 8. Test 2/c Swirl in Bay 4.

widen out considerably. Flow to bay 4 on the model still takes place through a course parallel to the weir from bay 7. Before reaching bay 4 it strikes against the bund and this bund will fail as the velocity of water against it in ordinary discharges is from 8 to 10 feet per second. In low discharges the downstream end of the *bela* may extend towards the weir bays 4, 5 and 6. On the left side bays 1 to 3, unless they are worked frequently, are bound to silt up.

Connecting bay 4 to the right channel does not lead to great improvement. Due to the bad approach of bay 4, this bay does not take its full share of discharge.

Determination of the distribution of flow and gauges during the passage of high flood discharges.

In order to determine the distribution of flow and ascertain damage likely to be caused by the passage of floods over the weir under existing conditions, tests were made on the model with the following discharges:

(*a*) 3,00,000 cusecs.

(*b*) 50,00,00 cusecs.

(*c*) 8,00,000 cusecs.

Passage of a flood of 3,00,000 *cusecs.*—A discharge equivalent to 3,00,000 cusecs was allowed to run in the model for about ten minutes. The arrangement of gate openings and dropping shutters was as follows :—

Shutters of bays 1, 2, 3, 6 and 7	All dropped.
Shutters of bay 5	Half.
Gate opening of left undersluices	.. 8·6 feet.
,, ,, right ,,	4·0 feet.
,, ,, central ,,	.. All up.

Water levels at different sites are given in the following table :—

Site.		Water level
Pocket	.. Gauge No. 13	R. L. 732·4
Groyne No. 1	.. 12	32·2
No. 2	.. 11	32·2
No. 3	.. 10	32·2
No. 4	.. 9	32·0
No. 5	.. 8	28·4 (masked).
No. 6	.. 7	32·0
No. 7	.. 6	32·0
Right Undersluices	5	32·8

No severe action apart from scour holes at one or two points was noticed at any point on the weir. The flood overtopped the *bela* and distributed more or less evenly over the entire width of the weir.

It may be concluded that if the *bela* is overtopped no serious damage may occur to the right portion of the weir. As the discharge was more on the right it flowed on to the left over the top of the *bela* and equalized itself. The distribution of the discharge during the flood is given below which confirms the above conclusions :—

Right side below weir	1,30,000 cusecs.
Left side below weir	1,61,000 cusecs.

Passage of a flood of 5,00,000 *cusecs.*—Next a discharge equivalent to 5,00,000 cusecs was run for about ten minutes. The river in flood discharge is shown in Photo No. 9.

Again the discharge was more or less evenly distributed. The upstream bund at groyne 5 remained intact on the model, though the water overtopped it. Distribution of the discharge obtained in the two halves of the weir are given below :—

Right side below weir	2,20,000 cusecs.
Left side below weir	2,57,000 cusecs.

No concentrated action seemed to take place at any portion of the weir and the right half was undamaged.

There was some action at the groynes of bay 4 and scour holes in front of bays 3 and 5. The following water levels were observed at different sites :—

Site.		Water level.
Pocket	Gauge No. 13	R. L. 734·8
Groyne No. 1	.. 12	736·0
No. 2	.. 11	734·4
No. 3	.. 10	735·8
No. 4	.. 9	735·8
No. 5	.. 8	736·0
No. 6	.. 7	735·4
Right Undersluices	.. 5	738·5

Passage of a flood of 8,00,000 *cusecs.*—A discharge of 7,78,000 cusecs was next run for 10 minutes. It was observed that as the river emerged from the Alexandra Bridge it bifurcated into two streams opposite spur B 2. The right current flowed along spur B 3 and hit against the upstream end of B 4. It then proceeded along spur I Middle Arm from

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Photo No. 9. 5,00,000 Cusecs Flood.
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which it was deflected to the centre where it was joined by the left stream.

Further down the stream at first bifurcated just upstream of spur E. Later, this point shifted to downstream of this spur. The *bela* was completely overtopped and there was strong action over it to begin with. Later a channel developed straight to Bay 4 and the action decreased.

Velocities were excessive in Bays 8,6,5,4,2 and left undersluices.

The distribution of discharge in the two arms of the river downstream was :—

Right	3,03,240 cusecs.
Left	3,01,260 do.

Water levels at all sites are given in the following table :—

Site.			Water level.
Pocket	..	Gauge No. 13	738·5 R. L.
Groyne No. 1	..	No. 12	737·8 ,,
No. 2	..	No. 11	738·0 ,,
No 4	..	No. 9	737·8 ,,
No. 5	..	No. 8	737·7 ,,
Spur E			742·2 ,,
,, H.G. U A.			744·2 ,,
,, G. H. L.A.			
,, I. L. A.			744·4 ,,
,, I. M. A.			747·4 ,,
Spur B 4			746·8 ,,
Spur B 3			740·2 ,,
Palkhu			753·0 ,,
Alexandra Bridge.			

The following points were observed after the run :—

The *bela* in front of spurs B 2 and B 3 extended downstream. Embayments between spurs B 2 and B 3 and B 3 and B 4 increased. A *bela* is formed between B 4 and I Middle Arm.

The main *bela* is shortened upstream by 800 ft. and reduced in width from the right.

The bund at groyne 4 was washed away and a passage formed to bay 4. Some silting up was noticed in bays 6 and 5. The main *bela* extended more into bays 3, 2 and 1.

Effect of the construction of training spurs in the left channel.

Effect of a single spur.—It has been stated in the earlier portion of this note that Mr. Nicholson's idea in constructing bay 4 was to obtain curvature of flow. This could not be achieved due to the growth of the *bela* in front of bay 4. The left channel, as has already been stated, flowed along the Palkhu spur and the left protection bund to the left undersluices and then to bay 4. As curvature of flow is undoubtedly one of the main factors in reducing silt entry into the canal, it was decided to construct a " T "-headed spur 500 feet long on the model at the position of the old Palkhu spur. The position of the spur is shown in Photo No. 10. The bed was moulded to the 1938 survey and discharges experienced in 1937 were run. It was found that though the construction of the spur has had the desired effect, the position selected was not very satisfactory. In the next test the spur was moved 400 feet upstream and the spur was made 700 feet long. This time the spur deflected the current and a channel to bay 4 started developing and the *bela* in front of it diminished. Discharges of 1938 were then run and it was found that during a flood of 1,46,000 cusecs, flow to bay 4 took place along the edge of the main *bela*. Downstream of this spur the velocity was so low that the channel silted to a length of about a thousand feet. A survey was made after closing down the model and it was found that the channel along the left bank was still much deeper than the one leading to bay 4.

Effect of two spurs.—With a view to still further improving the conditions a second spur was constructed at the position shown in Photo No. 11 and the model was run with the same discharges as in the previous case. The second spur succeeded in producing curvature of flow. The channel to bay 4 developed considerably and most of the *belas* in front of it were washed away. Conditions at the end of the test are shown in Photo No. 12.

While determining the quantity of silt entering the canal under different conditions a test was first made with no spur, then with one spur and finally with two spurs. The model was moulded in each case before starting to the 1938 survey and a discharge of 85,000 cusecs was run in each case. Each run lasted for 6 hours and at the end of this period the quantity of silt in the canal was measured. It will be seen from table 1 that the construction of one spur reduces the quantity of silt to less than 50 per cent while the construction of two spurs reduces it to 40 per cent. It may therefore be concluded that it is necessary to construct two spurs for obtaining a reduction in the quantity of silt entering the canal and for the development of the channel to bay 4.

TABLE 1.

MODEL OF KHANKI WEIR AT MALIKPUR.

Silt entry in the canal with the different methods of feeding the canal.

Canal Supply 10,000 Cusecs.

Description of the run.	Discharge in the right arm.	Discharge in the left arm.	*Left Pond.*		*Centre Pond.*		*Right pond.*		Silt (in cubic ft.) in the canal.	Proportion of silt in the two arms.
			Pond level	Gate openings.	Pond level.	Gate openings.	Pond level.	Gate openings.		
Without any spur	2,983,200	45. 144 cs.	732·0	6—Ist gate.	7315	7·5—all gates.	732·5	42—all gates.	0·56	L : R 1 : 1·8
With one spur at Palkhu arm.	,,	,,	,,	,,	,,	,,	,,	,,	0.28	1 : 1·3
With two spurs on the left arm.									0.20	1 : ·9

SUMMARY AND CONCLUSIONS.

(*i*) A model of the Khanki Headworks and the river Chenab for a length of 9 miles has been examined. It has been shown that the model reproduces faithfully the condition of flow of the prototype.

(*ii*) It has been found that if the present method of regulation is continued for another two years the left arm of the river will get choked up. The left arm also gets choked up if bay 4 is connected to the right channel.

(*iii*) The maximum advantage can be obtained from bay 4 by making a cut in the *bela* from the right and developing the cut.

(*iv*) The most suitable discharge in the left arm for optimum silt entry in the canal is about 40,000 cusecs. Above this discharge the quantity of silt passing into the canal increases considerably.

(*v*) The most suitable water surface slope between Palkhu spur and gauge No. 13 for optimum silt entry in the canal is 1/4000.

(*vi*) Connecting bay 4 to the right channel by dismantling the existing bund and making a new bund at groyne 3 only makes matters worse.

(*vii*) It has been shown that by feeding the canal from the right more silt enters and parallel flow causes deep scour holes in front of the weir.

(*viii*) During the passage of high floods the central *bela* is overtopped and the distribution of flow is more or less uniform. The partition bund is washed away but no considerable damage occurs on the model.

(*ix*) It has been found that for minimum silt entry in the canal it should be fed from the left channel. Therefore the left channel should be maintained. In order to achieve this an attempt has been made to develop a straight channel to bay 4 and allow a minor channel to exist leading to the left undersluices, by constructing two "T"-headed spurs in the left channel, one at the upstream end of the old Palkhu spur and the other at a distance of 3,100 feet from the weir line.

This arrangement seems to give the most satisfactory results.

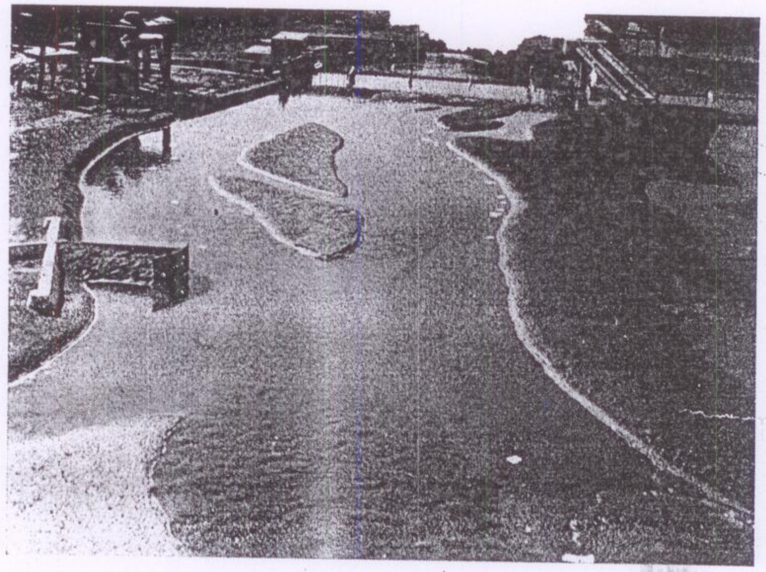


Photo No. 10. Test with one spur 500' long at the middle of old Palkhu Arm.

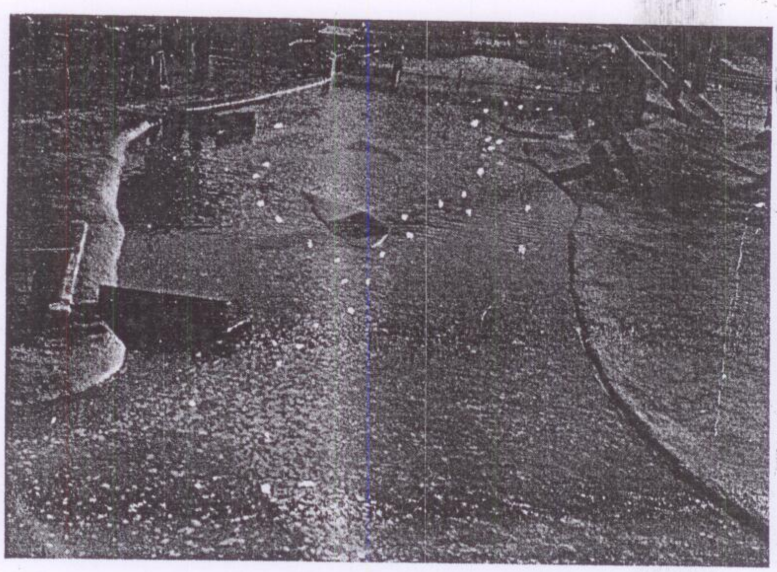


Photo No. 11. Test with two spurs.
Photograph showing the water being deflected towards Bay 4.

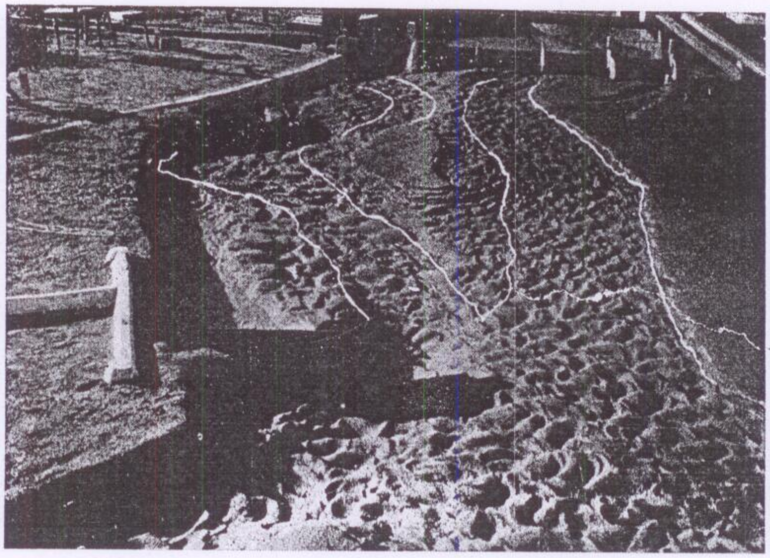
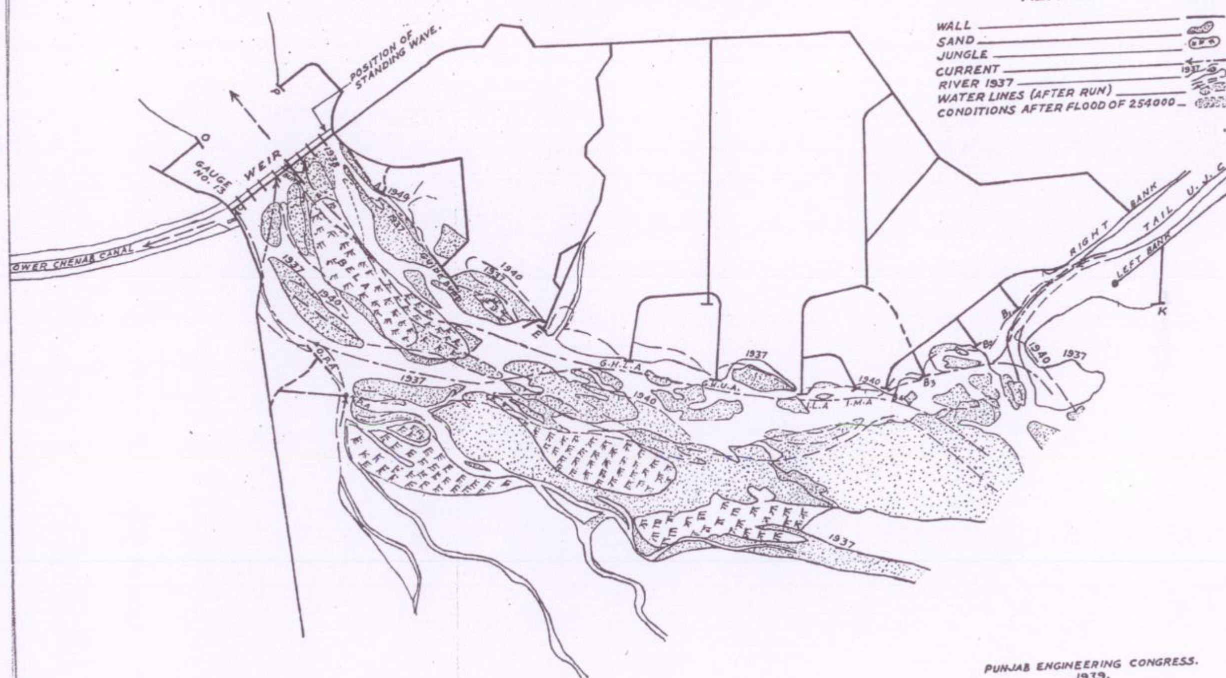


Photo No. 12. Test with two Spurs.
Photograph showing the development of channel to Bay 4.
The Punjab Engineering Congress, 1939.

PLATE I
PAPER NO. 227

KHANKI HEADWORKS

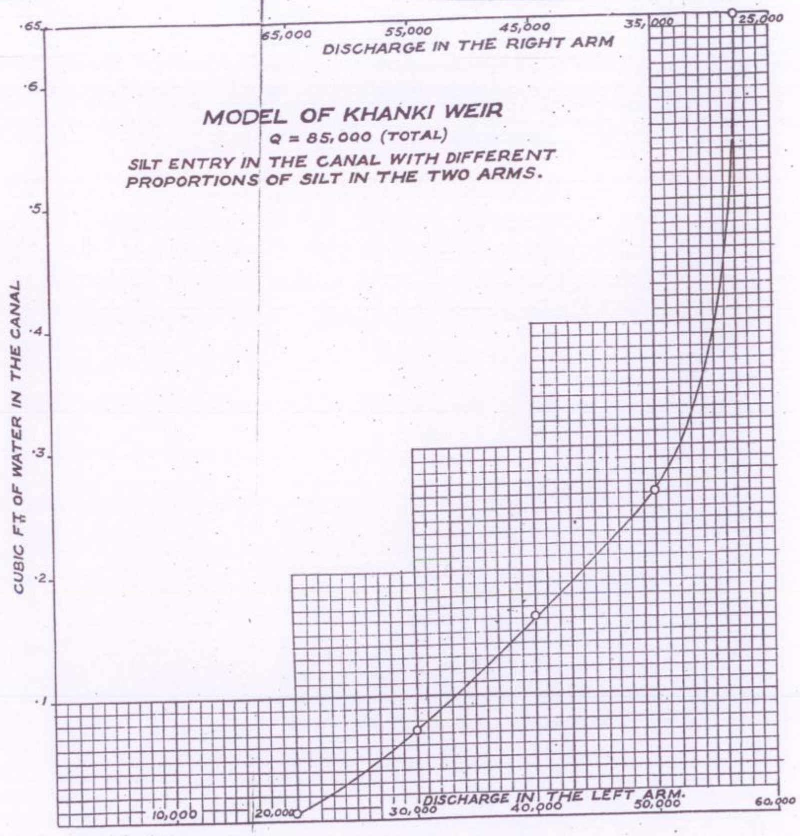
SCALE 2·91" = 2 MILES APPROX.



PUNJAB ENGINEERING CONGRESS.
1939.

PLATE II

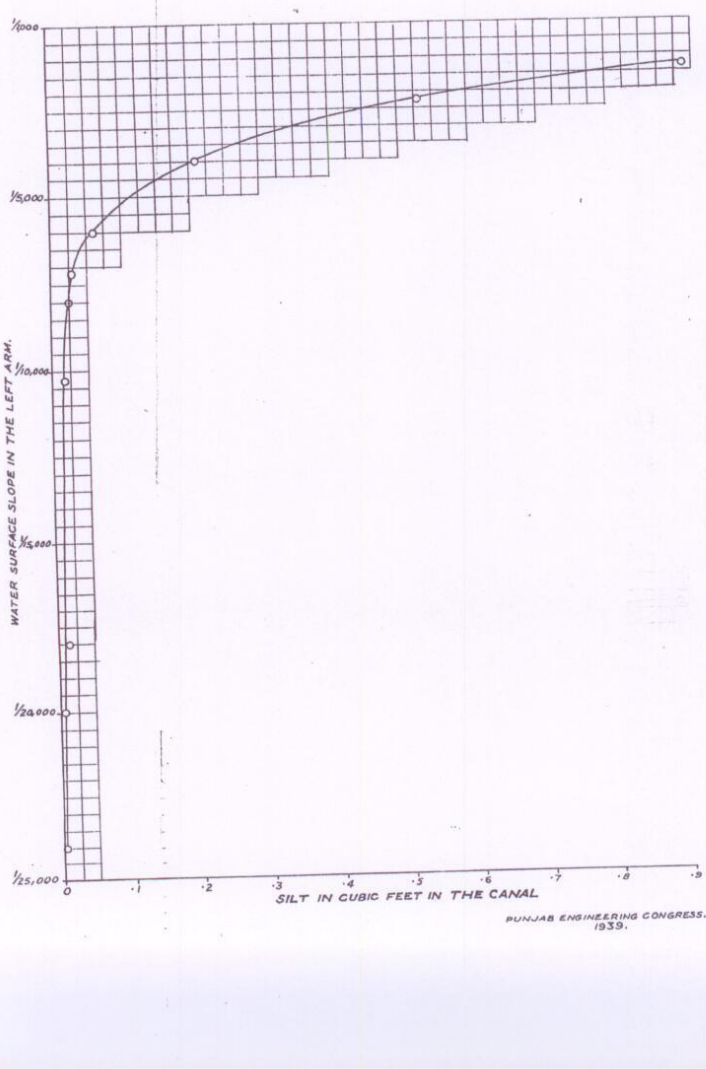
PAPER NO. 227



PUNJAB ENGINEERING CONGRESS. 1939.

PLATE III
PAPER NO. 227

DIAGRAM SHOWING RELATIONSHIP BETWEEN SILT ENTRY IN THE CANAL & THE WATER SURFACE SLOPE IN THE LEFT ARM.



PUNJAB ENGINEERING CONGRESS.
1939.

DISCUSSION.

The **Authors** introducing their paper said that the results obtained on the first model only had been given and the work extended over a period of about a year. As would be seen from the paper, experiments were carried out on the model to investigate the possibilities of adopting the following two methods at Khanki :—

(1) Overdeveloping the right channel and passing surplus discharge in this channel through Bay 4; thus connecting Bay 4 to the right portion of the weir.

(2) Developing the left channel by creating a main channel along the left edge of the central bela to Bay 4 and a subsidiary channel to the left undersluices.

(1) Overdeveloping the right Channel.

For this method tests were firstly carried out by making a leading cut from the right channel to Bay 4 through the central bela and secondly by dismantling the bund at Bay 4 and constructing it at Bay 3. Of these two, the latter was found to be unsuccessful as the approach conditions were such that sufficient discharge could not be diverted to Bay 4. By making a leading cut through the central bela and developing it by means of keeping high levels on the right side and very low in the central undersluices, a channel to Bay 4 from the right carrying even the designed discharge for Bay 4 could be obtained. This method had also one defect. With the leading cut to Bay 4 developed, the portion of the central bela downstream of the leading cut and the dividing bund at Bay 4 could easily be washed off during the passage of high floods, ultimately creating conditions similar to those existing at Marala. Running the model for some time under these conditions showed that the main channel which, before the leading cut was made, existed in front of Bay 8, now shifted to Bay 6. The river bed in front of Bay 8 showed heavy silting up. One of the important conclusions obtained, after running the model for a period equivalent to one year was that if bay 4 was connected to the right channel by making a leading cut by allowing the dividing bund to be washed away, not only that the main channel which now existed in front of Bay 8 would shift to Bay 6, but Bay 8 would be masked by the presence of belas in front of it. The left channel would also get choked under these conditions of flow and the canal could only be fed from the right by inducing parallel flow along the weir. It was found on the model that the parallel flow brought more silt into the canal than that entering the canal by adopting straight flow. The tests were also repeated in the presence of the Executive Engineer, Khanki Division and they only confirmed the conclusions obtained previously.

(2) Developing the left channel.

The alternative method studied was to develop the left channel. For the past few years, the discharge in this channel had been restricted to about 30,000 cusecs with a view to obtain less silt into the channel. This method of regulation had resultd in the development of a number of fresh belas in the left channel in extension of the main bela, and the channel straight to Bay 4 which existed in 1937 got choked up. Efforts were made to develop the partially choked up channel to Bay 4. The scheme of development of the left channel was as follows :—

(*i*) to create a major channel straight from the Palkhu to Bay 4 and (*ii*) a minor channel from the Palkhu to the left undersluices. This channel was to carry discharge just enough to feed the canal.

The most successful method of achieving the above was to construct a spur at the Palkhu such that it deflected the main stream on the left into the Creek leading to Bay 4. The presence of the spur also helped in washing away some of the belas in the left channel. When the model had been running with the spur in position for a period equivalent to one year, it was found that, two channels existed in the left arm of the river—a major channel to Bay 4 and a minor one to the left undersluices. Another spur at a point 2000 ft. upstream of the head regulator was also constructed to cause further deflection of the current to Bay 4. Silt entry in the canal in the presence of these two spurs was insignificant. The method of developing the left channel was found superior to the first.

The Chief Engineer's original order asked for the investigations of seven problems connected with Khanki Headworks. Four of these problems were examined on this model. The remaining three problems were as follows :—

(*i*) How far the present silt excluder was performing its function of excluding coarse silt from the canal and what discharges should be passed through the silt excluder tunnels at different stages of the river for optimum results.

(*ii*) What additions or alterations, if any, were required in the existing silt excluder to make it more useful.

(*iii*) To investigate as to what extent heading up of supply at gauge in the pocket helped to exclude silt in the canal.

In order to study these, a large model to a scale of 1/50 had been constructed. It was intended originally to incorporate all the tests of the 2nd model in this paper. Unfortunately due to rains, the work on the 2nd model was held up for over 2 months. This model was constructed without distortion and represented the whole of the weir, the undersluices and River Chenab upto spur E. On the downstream side the model was extended to include the spurs O and P. Photos No. 13 and 14 shewed the model during construction. Photo No. 15 shewed

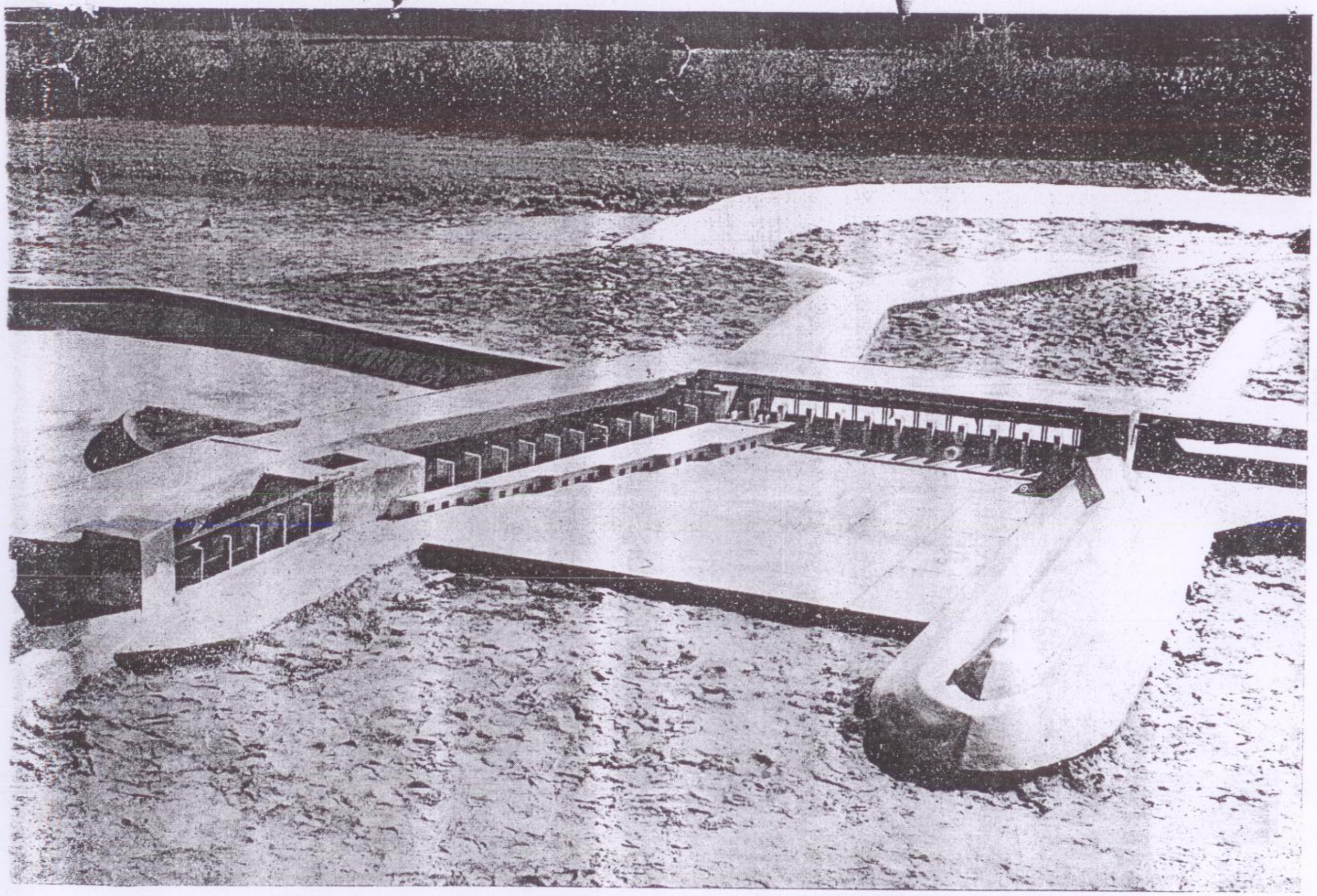


Photo No. 13—Left undersluices and canal head regulator.

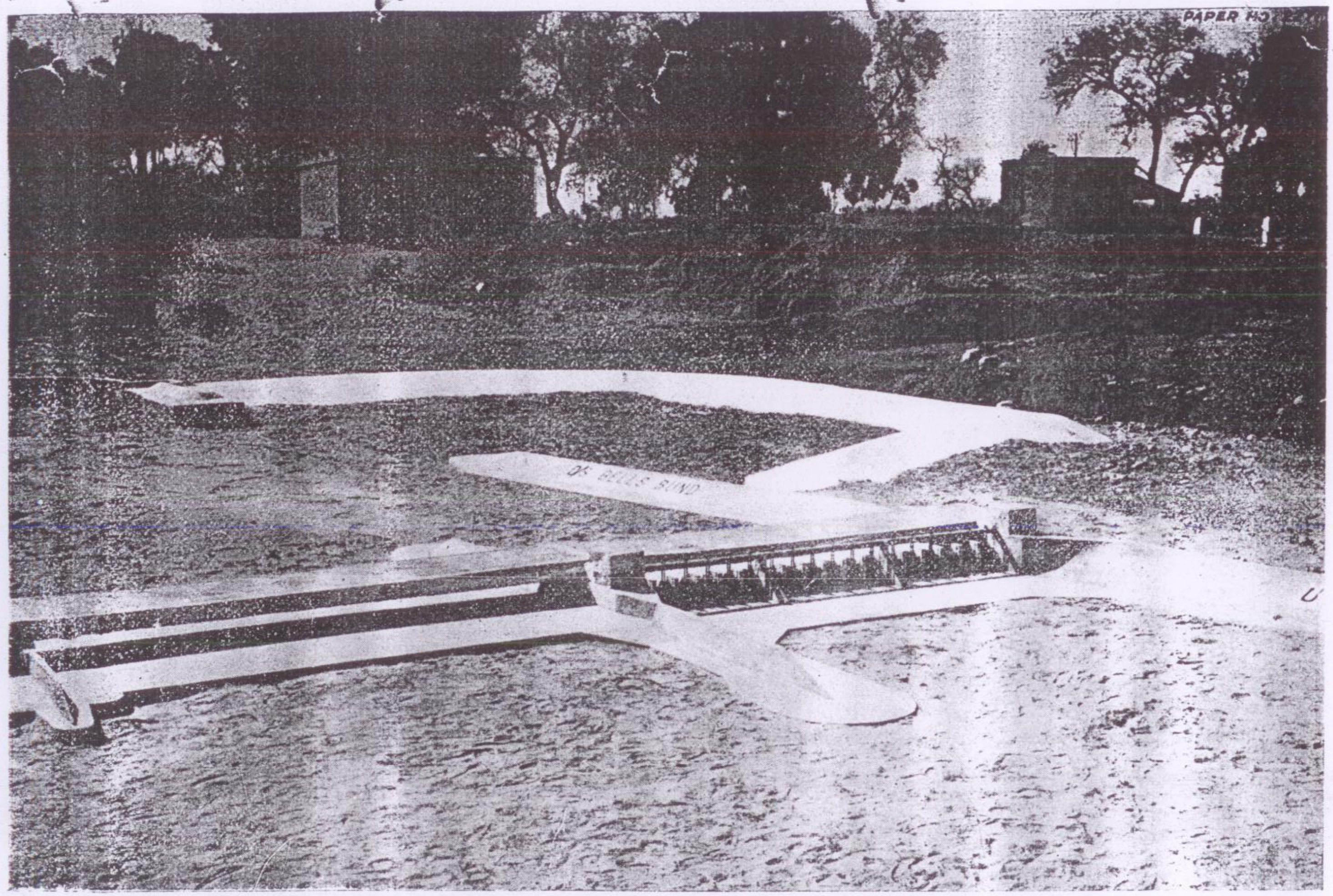


Photo No. 14—Right undersluices, bells bund and spurs downstream.

Photo No. 15—Model in running conditions.

the model in running condition after completion. It was unfortunate that further tests were not available.

The Authors took the opportunity of thanking Dr. E. McKenzie Taylor, Director of Irrigation Research, Punjab, for his direction, help and guidance at all stages during the course of the investigation. But for his invaluable help it would not have been possible to obtain these results.

Dr. **N. K. Bose** stated that as the authors had remarked on page 175 of their paper, these experiments were started by the speaker in March, 1938. Similar experiments were first instituted by the speaker on the River Chenab in connection with the Haveli Project. As the speaker's method of carrying out such experiments on River models was different from the methods applied in Europe and America, it would be interesting to give a detailed description of the method applied in these experiments at Malikpur. In river models M. Fargue, Osborne Reynolds, Vernon-Harcourt and Engel were the pioneers. In Germany, the methods adopted by Krey and Rehbock consisted in building the bed and the banks of the river in clay in cement and forming the contours of the bed with loose incoherent sand to a depth to which the maximum possible scour could reach. In England, Gibson has been mostly busy with tidal models of rivers whose beds and banks were built in cement and sands spread over those portions of the bed where some sand movements were observed in the prototype. In America, Vogel also built his models with cement, laying sand on the bed forming shoals and bars. In India the speaker believed that Inglis also built his model with clay on the banks, only spreading sand on the bed. The speaker had always been of opinion that if the banks in the model be made of clay or cement which could not be attacked by the flow of water, then the behaviour of the model river so far as its silting and scouring actions were concerned would be fundamentally different from that of the prototype, so he had always built his models of rivers in incoherent sand, putting clay in those portions where it was known that the banks and belas had been resisting river action for a long time. Such cases occurred frequently in rivers and must be familiar to river engineers. Experience would only show how far the speaker was correct.

It was desired to investigate on models the following points in connexion with the Headworks at Khanki :—

What training works were necessary and how should the headworks be regulated so that :—

(1) The flow over the weir was uniform in high floods.

(2) In low supply the flow in the left arm of the river should be enough to feed the canal.

(3) Entry of silt into the canal should be minimum at all times of the year.

These problems were such that they could not be dealt with in one model unless the size of the model was made so large that the velocities in the pocket were high enough to keep all silt coarser than 0·07 mm. in diameter in suspension. At the same time the model had to be long enough to include a stretch of the river upstream of the Headworks so that the inlet conditions of the river were well defined and well known. Accordingly, it was decided to build two models, one for studying conditions (1) and (2) and another for condition (3) enumerated above. For this purpose the first model was built so as to include a stretch of the river between the Khanki Headworks and the railway bridge at Wazirabad where the river flowed through a well defined channel and where gauges and discharges were known accurately for a number of years. The importance of reproducing the entry conditions correctly was at once manifest when initially the model was being tested for the reproduction of gauges. As was well known and could also be seen from the survey plan of the river, there were a number of spurs upstream of the headwork each provided with gauges that were read daily. Downstream of the railway bridge a cross-section of the river bed was known but nothing was known how the river approached the bridge, so that it was very difficult to reproduce the gauge at the railway bridge correctly and consequently all the spur gauges showed considerable variation from the prototype values for corresponding discharges. Consequently, the flow through the bridge was manipulated by adjusting gates at the entrance of the model and the required gauges were obtained at the railway bridge which immediately reproduced the spur gauges correctly.

Conditions of the problems being such that the whole stretch of the river between the Alexander Bridge and the headworks had to be modelled, the dimensions of the available span at the Experimental Station at Malikpur decided the horizontal scale. It was found that a horizontal scale ratio of 1/200 would suit, so that :—

$$l = \text{horizontal scale ratio} = 1/200.$$

The speaker generally calculated the vertical scale ratio from the following equation of Lacey's

$$S = 370{\cdot}68 \times 10^{-6}\ F^{3/2}.\ R^{-1/2}$$

which gives for rivers—

$$d = \text{depth scale ratio}$$
$$= f^{\cdot}\, l^{2/3}.$$

where f is the ratio between the silt factor in model and prototype. For the same silt as was found in the river at Khanki, $f=1$, so that $d = l^{2/3}$.

Similar relationship might be derived between the two-scale ratio d and l from Manning's, Kutter's or Winkel's formulae. So that he obtained d = 1/34. This gave a distortion of 5·88 but as the silt actually used in the model was slightly coarser than that of the prototype a distortion of 6·67 was given

$$\therefore d = 1/30.$$

This decided the two length scales of which the depth scale had often to be modified if it was found that the reproduction of the bed contours was not satisfactory while deducing the time scale. Next, the scale ratio that was to be found was the time scale which determined the duration for which a certain discharge in the model was to be seen to reproduce the same bed conditions as was obtained in the prototype for corresponding discharges. For determining the time scale, the model was run for the three scales mentioned by the Authors on p. 175.

1½ hours on the model = 1 month in the prototype.
3 hours ,, = 1 ,, ,,
4½ hours ,, = 1 ,, ,,

For the determination of the correct time scale, conditions at Khanki were very suitable. Perhaps many of the engineers present knew that a cut in the upstream bela was developed in the summer of 1934. The rate of development of this cut in the model compared very satisfactorily with that in the prototype of which accurate observations were available. This happened for the time scale, 4½ hours on the model = 1 month in the prototype.

For the determination of the time scale specially for such models, no suitable theoretical formulae had been developed up till now. For the tidal model, Gibson found that the theoretical time scale worked satisfactorily in his models, but Krey and Rehbock who had worked on similar models as the one under discussion, arrived at the conclusion that at the present stage of knowledge of such model experiments it was not possible to derive any theoretical formulae for time scale. Workers at the Wicksburg Experimental Station, U. S. A. had made some attempt to deduce a theoretical formula for time scale but Vogel who was the Director of the Station had definitely said that no such theoretical relationship was possible at the present stage of development of River Model Experiments. The Science of River Model Experiment was of very recent growth and accumulation of data from model experiments was essential before any theory could be built upon it. At this stage, it was essential that engineers personally acquainted with the prototype conditions should be intimately associated with a mathematical physicist in the working of such a model. The speaker's thanks were due to Mr. Kapur whose intimate knowledge of the local conditions had helped him in detecting the deviations of the model while working out its scale ratios.

There was another scale ratio that had to be still worked out. It was the silt scale; that is, the quantity of silt that had to be injected in the model so that the silt equilibrium conditions were attained. It was found that 54 cu. ft. of silt had to be injected in the course of a year's run of the model. The rate of silt injection was varied with discharges in the river—the total quantity being 54 cu. ft. per year.

The model was now ready for solving the problems set forth in the beginning of the discussion. The speaker had looked upon river model experiments as consisting of two parts. In the first part the model had to be built up so that it could reproduce all the conditions that were known to occur in the prototype under varying stages of discharges. Having thus shewn that the model was true to nature, the second part of the experiments started when different hypothetical combinations were artificially set up in the model and the model was expected to bring out the correct results. After the first part of the experiment was over, the speaker handed over the model of the Authors when he went on leave. He understood that Mr. Kapur had been actively associated with the second part as well. He would very much like to know whether the solutions as worked out by the model agreed with the results that Mr. Kapur expected from his experience of the headworks. It was only by comparing them that insight into the intricacies of these models could be gained.

Mr. **S. H. Bigsby** intervened to state that in his opinion the Paper was somewhat premature, though it would have not been premature had the heavy rain during the last few weeks not prevented the completion of the experiment. He explained that the remedy, advocated as a result of the tests described in the Paper, was so drastic that an Engineer would hesitate to accept it without a further proof. As Chief Engineer in charge of Khanki, Mr. Bigsby had ordered further investigations which entailed the construction of a model to a larger scale. The object of these investigations was to ascertain the effect of building smaller spurs in place of the one spur which was to jut out into the river and which would clearly be difficult to maintain.

Mr. **Kanwar Sain** remarked that the experiments at Malikpur were instituted on his suggestions when the Haveli Project was sanctioned. A sum of Rs. 10,000 was also obtained from the Chief Engineer, Haveli Project, for this experiment. The river model was made in order to test the position of the guide banks as well as to obtain some useful hints regarding the river diversion. Dr. Bose, after a large number of trials and errors, was able to fix suitable scales according to which he was able to reproduce conditions regarding the upstream water levels by running average monthly discharges on record for the last 5 years. This experiment was helpful to a certain extent. The second part of the experiment was to construct a large scale model of the pocket and the various arrangements for excluding silt. It must be said very frankly that the results regarding the silt were far from convincing. The technique of these experiments had to be improved a good deal before these experiments could be expected to give any reliable results regarding silt entering into the canal. The third part of the experiment was to determine suitable methods for killing the downstream energy below the falls. In this respect these experiments proved useful and could be taken as a very good guide.

Mr. **B. K. Kapur** stated that members were thankful to the Authors for giving an opportunity of discussing a new method of approach to the important problems of River and silt control by means of Mode Experiments. To his mind the model experiments give only a qualitative indication of the behaviour of rivers under the conditions respresented by the models, but from the conclusions arrived at by the author even these expectations had not been quite justified in some respects.

For instance there seemed to be no possibility of the left arm of the river getting choked up if the present method of regulation were continued, not only for two years but for an indefinite period. In spite of the forecast of the authors, during a recent freshet of about a lakh of cusecs, more than half the discharge passed through the left arm.

The conclusion that by feeding the canal from the right, more silt would find its way into the canal seemed erroneous. The longer the feeding channel the flatter must be the slope and the finer the silt and therefore according to the findings of the authors less silt would enter into the canal. This was confirmed by the actual experience at Marala. Probably the authors failed to reproduce the feeding conditions at Marala and hence their erroneous conclusion. Again, the conclusion that during the passage of high floods of over three lacs and more, the central bela was overtopped and that the distribution of flow became more or less unifom was also not correct. In a flood of 264,000 cusecs last hot weather, which overtopped the bela at several places the right arm got as much as 162000 cusecs with a gauge level of 734·6. The indication given by the model experiment with a flood of 3 lacs was a discharge of 130,000 cusecs in the right arm with a gauge of only 732·0. This was a very serious discrepancy which vitiated the results of the experiments.

As regards the effect of the construction of spurs, it seemed necessary to run the model under various River conditions for a number of years, before accepting the results, because the past history of the Palkhu Spur showed that the proposed spurs might subsequently throw the River entirely towards the right and mask the canal head regulator unless they were supplemented by other spurs higher up to give a definite direction to the set of the River.

Mr. **G. R. Sawhney** remarked that the Punjab Irrigation Research Institute and the Authors deserved thanks for keeping the Congress well supplied with papers suitable for really good discussions. He was afraid however that while miniature models in which every thing except