A similar series of experiments was carried out with divide walls of varying lengths constructed at the seventh pier.

A comparison of the quantities of silt entering the canal for the different conditions is given below :—

Silt entry into the canal with different lengths of divide wall and with different discharges.

Length of divide wall.	Discharge.	*Silt in the canal in lbs.* Divide Wall at 4th pier.	Divide Wall at 7th piers.
	150,000 cusecs.		
600 feet		8·22 lbs.	2·7 lbs.
450 feet		4·02 ,,	1·4 ,,
300 feet		4· 3 ,,	2·2 ,,
	200,000 cusecs.		
600 feet		22·2 ,,	6·0 ,,
450 feet		12·4 ,,	4·0 ,,
300 feet		9·5 ,,	4·4 ,,
	250,000 cusecs.		
600 feet		86·0 ,,	15·7 ,,
300 feet		23·4 ,,	5·1 ,,

Conclusions. From an examination of the above data the following conclusions were derived :—

(*i*) A divide wall of 300 feet in length induces minimum silt entry into the canal.

(*ii*) The silt entering the canal when the divide wall is constructed at the seventh pier is much less than that with the divide wall at the fourth pier.

(*iii*) The velocities in the pocket with the divide wall at the fourth pier are much higher than those obtained when the divide wall is at the seventh pier.

(*iv*) A silt wave forms along the left guide bank up to a point 1,000 feet from the weir. After this point the silt wave travels towards the bays on the right side of the undersluices. When a divide wall is constructed at the fourth pier it intercepts the silt wave and diverts the silt into the canal. With a short divide wall at the seventh pier their is no interception of the silt wave and, therefore, less silt enters the canal.

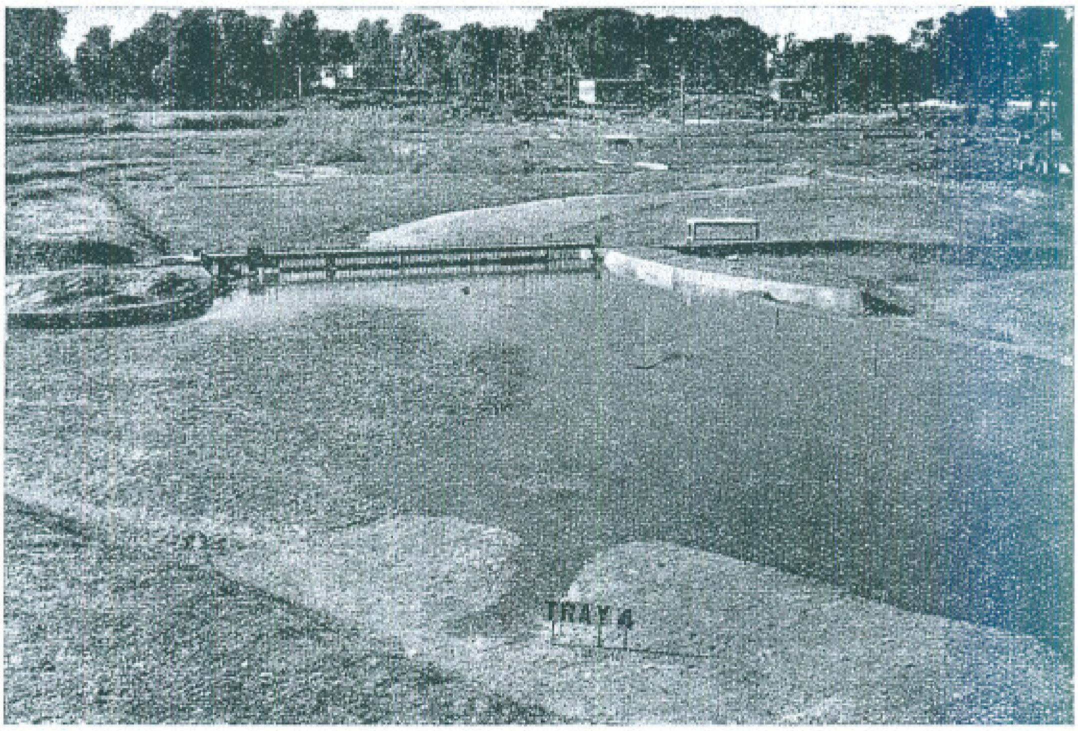
Accordingly a divide wall 300′ in length was constructed at the 7th pier at the Kalabagh Headworks. Since the river is not yet diverted on to the weir it is not possible to check the model results. This will be done as soon as the weir starts working.

D. Exclusion of shingle and silt, carried by the rivers, from the Canals.

Methods of exclusion, of shingle and silt, carried by the River Jumna, from the Western Jumna Canal, examined on a model of the River Jumna and the Tajewala Headworks, will be described.

RIVER INDUS AT KALABAGH HEADWORKS.

Fig. 14.



A view of the model of the River Indus 5 miles above and 3 miles below the Kalabagh Headworks. The model represents the Kalabagh Weir, the undersluices and the guide bunds. This is after the river diversion.

Scales adopted :—

Horizontal	— Model to prototype	...	1 to 100.
Vertical	— Model to prototype	...	1 to 15.
Exaggeration	... ...	...	6·66
Area occupied by the model		...	700′×350′.

Discharge on the model corresponding to the maximum flood discharge on the prototype ... ... 200 cusecs.

The problem. Large quantities of shingle and sand have been entering the Western Jumna Canal at the head since the remodelling of the canal carried out in 1939, in order to increase the full supply discharge from 6,000 to 9,000 cusecs. The increase of 50 per cent discharge in the canal resulted in a 300 to 400 per cent increase in the quantity of shingle and sand entering the canal.

The problem, therefore, was to reduce the shingle and sand, entering the head, for, if the shingle and sand were allowed to enter the canal at this rate it was feared that the canal capacity would be seriously reduced in a very short time.

The Model. A model of the River Jumna for a length of three miles above and half a mile below the Headworks was constructed.

The items reproduced. The following items were reproduced on the model :—

1. The Head Regulator of the Western Jumna Canal and the Canal downstream of the regulator for a length equivalent to 4,000 ft.
2. The Western Jumna Canal undersluices.
3. The old weir and the Block Bar Spur.
4. The new weir and the Groyne wall.
5. All the training spurs between the Hathni Kund Gauge and the Tajewala Pocket.

The Scales Adopted. The following scales were adopted :—

1. Horizontal : Model to prototype 1 to 40.
2. Vertical : Model to prototype 1 to 12.
3. Exaggeration : 3·33

The Equipment. An elaborate arrangement of straight edge trollies was made over the pocket and the entire length of the old weir. The straight edges were fixed to iron rails which were supported on round pillars. Pitot tubes for taking velocity observations and pointer gauges for recording water levels were fitted on the trollies. By this arrangement accurate observations could be made in the pocket and in the river upstream of the pocket. In addition, there were constructed 10 gauge wells at important points for recording the river levels. Each gauge well was fitted with straight edges and a point gauge. A view of the model fitted with straight edge trollies is shown in Fig. 15.

Shingle Feeder. For feeding shingle and silt an automatic feeder was used.

The Bed Material. The material constituting the bed of the model varied at various points. The high belas were made of large size shingle 2″—3″ diameter while in the main creeks the bed consisted of shingle between $\frac{1}{4}$″ and $1\frac{1}{4}$″ size. The procedure adopted in determining the correct grade for the bed was as follows :—

4. A mixture of different grades of material was placed in the bed and the model was run with varying discharges. In each discharge material downstream of the regulator and the undersluices was collected and analysed. The same grade of material as collected downstream was added at the upstream section of the model in each discharge to maintain the bed equilibrium.

Checking the Model. The model was run and checked from previous two surveys and was found to be reproducing the conditions accurately.

Slow Motion Picture Study. There are certain stages of flow which last for a very short time on the model and cannot be studied in detail. For this purpose a slow motion picture during the operation of the model is taken with a *superspeed cine camera* which gives 128 pictures a second.

The film is then examined on the screen with the normal speed of the projector and with the speed of the projector considerably reduced so that each frame can be examined. This method of studying certain conditions of flow on the model, which otherwise cannot be examined has proved to be very useful.

Methods of Exclusion examined. The different methods of exclusion of shingle examined are divided into two parts as below :—

PART I. Methods of exclusion examined at point 'A' Island.

PART II. Methods of exclusion examined in front of the Head Regulator of the Western Jumna Canal.

PART I. Methods of exclusion of shingle examined at point 'A' Island were :—

1. Constructing a shingle bar or a weir between the nose of the Gordon's Groyne and the Block Bar Spur.
2. Removing the Block Bar Spur at Point 'A' Island.
3. Constructing shingle deflectors in the river above the nose of the Gordon's Groyne and providing a set of undersluices at the Weir.

The most satisfactory results were obtained by constructing a series of shingle deflectors.

First of all one shingle deflector was constructed and the quantity of shingle and silt entering the canal in the presence of the deflector was compared with that passing into the canal in the absence of the deflector. Then more deflectors were added and the spacing, the height and the shape was determined. The criterion of a satisfactory design was the amount of material entering the canal. The arrangement with which no shingle passed into the canal was considered to be the most suitable[1].

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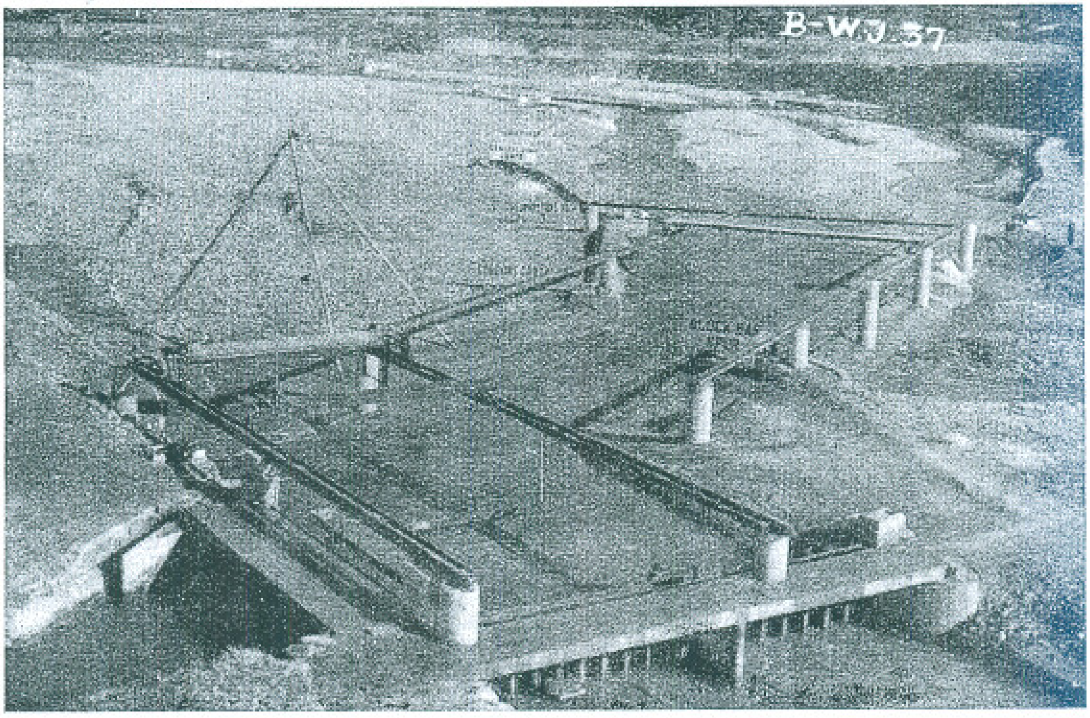
1. Studies in the Methods of Exclusion of Shingle and Sand carried by the River Jumna from the Western Jumna Canal.

PART I. Methods of exclusion examined at point 'A' Island, by Harbans Lal Uppal, M.Sc., Ph.D.

RIVER JUMNA AT TAJEWALA HEADWORKS.

Fig. 15.



A view of the model of the River Jumna and the Tajewala Headworks.
Scales adopted :—

Horizontal	1 to 40.
Vertical	1 to 12.
Exaggeration	3·33
Area occupied by the model	500′×200′.

Model fitted with channel iron and straight edges for taking accurate measurements.

Model discharge corresponding to maximum flood discharge on the prototype ... ... 140 cusecs.

The most suitable design. The most suitable design consisted of four deflectors arranged as shown in Fig. 16. The height of the deflectors varied from the upstream to the downstream end from 2 ft. to 1·5 ft. In the presence of the deflectors it was shown that:

(*a*) no shingle entered the canal.

(*b*) the top water went towards the pocket.

(*c*) the whole of the charge added passed over the weir into the river.

The floor between the deflectors was next made smooth. With the smooth floor the efficiency of the deflectors was considerably increased and no material deposited on the floor in between the deflectors.

Discharge used by the Deflectors. For working the deflectors it was necessary to escape about 1,200 cusecs over the weir. For this purpose gates were constructed at the weir at the downstream end of the deflectors. In this portion the weir crest was lowered.

Sluicing Operations. With the low river discharges when it is not practicable to always escape water over the weir further experiments were carried out. It was shown that a sluicing operation should be carried out at least once a week in the low river discharges, in order to flush the deflectors of any deposit which occurred between them when no escapage of water was taking place over the weir. It was shown that with the depressed weir lowered to R. L. 1,060·5 a successful sluicing operation could be carried out with a discharge equivalent to 8,000 cusecs above the Eastern Jumna Canal.

The effect of the construction of the deflectors on the river regime. A comparison of the river sections 600 to 1,000 ft. up weir with the lined bed of the deflectors showed that the bed of the deflectors was at the general bed of the river. The effect of the construction of the deflectors on the river regime would not be very great.

PART II. Methods of exclusion examined in front of the Head Regulator of the Western Jumna Canal.

Shingle and silt excluders constructed in front of the Head Regulator

The following methods were examined :—

1. The Khanki Type Excluder with a continuous slit near the top. *Two tunnel system.* Experiments carried out with an excluder covering four bays of the canal regulator from 12 to 9 showed that for conditions of flow at Tajewala this design did not work at all. The tunnels became choked in a very short time. The design is shown in Fig. 17.

2. The Khanki Type Excluder with a continuous slit near the top. *Four tunnel system.* A four tunnels excluder was next examined. This design also met with little success. The tunnels became choked as shown in Fig 17-A.

3. The Khanki Type Modified Excluder with a series of openings near the top.

One tunnel system. A modified Khanki Type Excluder with a single tunnel and a series of openings near the top was also examined. It covered four bays of the regulator from 12—9. The width was five ft. and the height varied from two ft. at the upstream end to four ft. at the downstream end. This gave a slope of 1 in 55 in the bed of the tunnel As shown in Fig. 17-B there were eleven openings $10' \times 1 \cdot 5'$ at the front, and an opening provided from Bay 8. A detailed examination was made and the conclusion obtained was that the tunnel was not at all effective in excluding any shingle or silt.

First of all the opening from Bay 8 became choked due to a deposit of shingle which occurred there. Later on, the whole of the tunnel became completely shingled up. In the final conditions the ramp in front of the tunnel was in level with the top of the tunnel and a considerable quantity of shingle and sand entered the canal, through the bays of the canal in front of which the tunnel was constructed.

Experiments were carried out to determine the effect of extending the roof of the tunnel on the efficiency. It was shown from the experiments that extending the roof up to 3 feet beyond the original width did not improve the efficiency.

4. A new design of shingle excluder with openings at a few selected points near the bed. A new design of shingle excluder was developed.

The essentials of the new[1] design were as follows :—

(*a*) Concentrated suction at a few selected points.

For a shingle excluder it is necessary to have a smaller area of openings in order to concentrate suction. If the openings are at a few selected points the draw would be great and the working would be much more effective than that obtained by adopting a continuous opening or a slit over a long length.

(*b*) *Front openings and no side openings*. The directions of flow influence considerably the design of the shingle excluder tunnels. In this particular case the openings into the tunnels from the Point 'A' Island side as shown in the plan become ineffective due to the unfavourable curvature of flow.

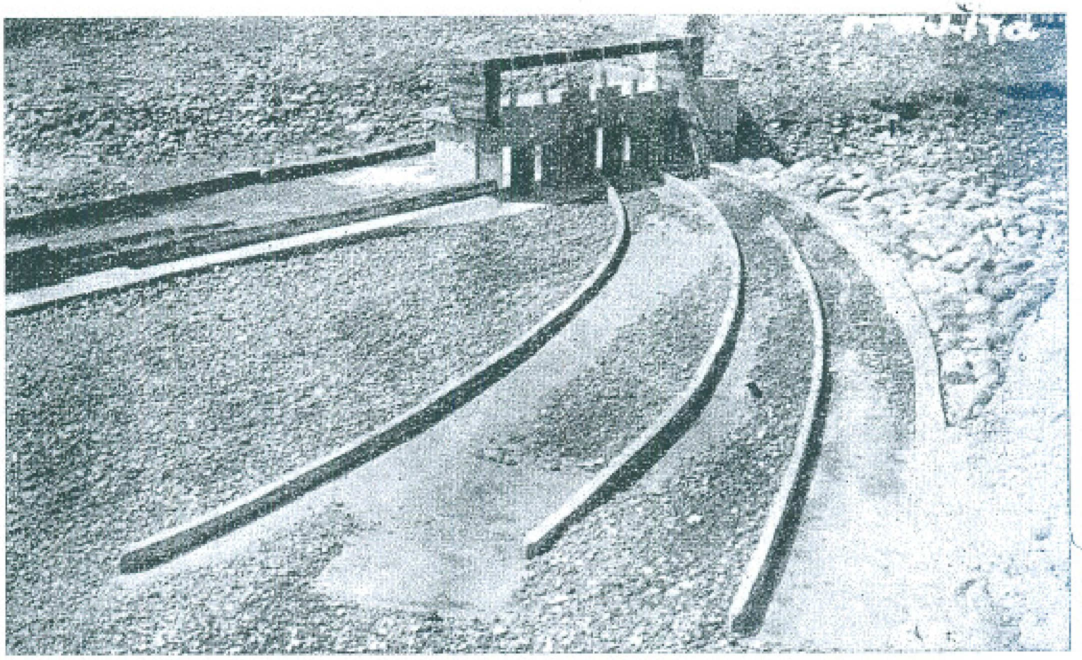
The flow first takes place parallel to the regulator and then undergoes distortion. The openings from Point 'A' Island side under these conditions lie on the inside of the curve. Eddies form there and shingle

1. Studies in the Methods of Exclusion of Shingle and Sand, carried by the River Jumna, from the Western Jumna Canal.

PART II. Method of exclusion examined in front of Head Regulator, by Harbans Lal Uppal, M.Sc., Ph.D.

SHINGLE DEFLECTORS.

Fig. 16.



This photograph shows a series of deflectors at point 'A' island to exclude shingle and silt carried by the River Jumna from the Western Jumna Canal. Four deflectors—floor paved, upstream R. L. 1,064·0 downstream R. L. 1,060·5 weir for a length of 180 ft. lowered to R.L. 1,060·5.

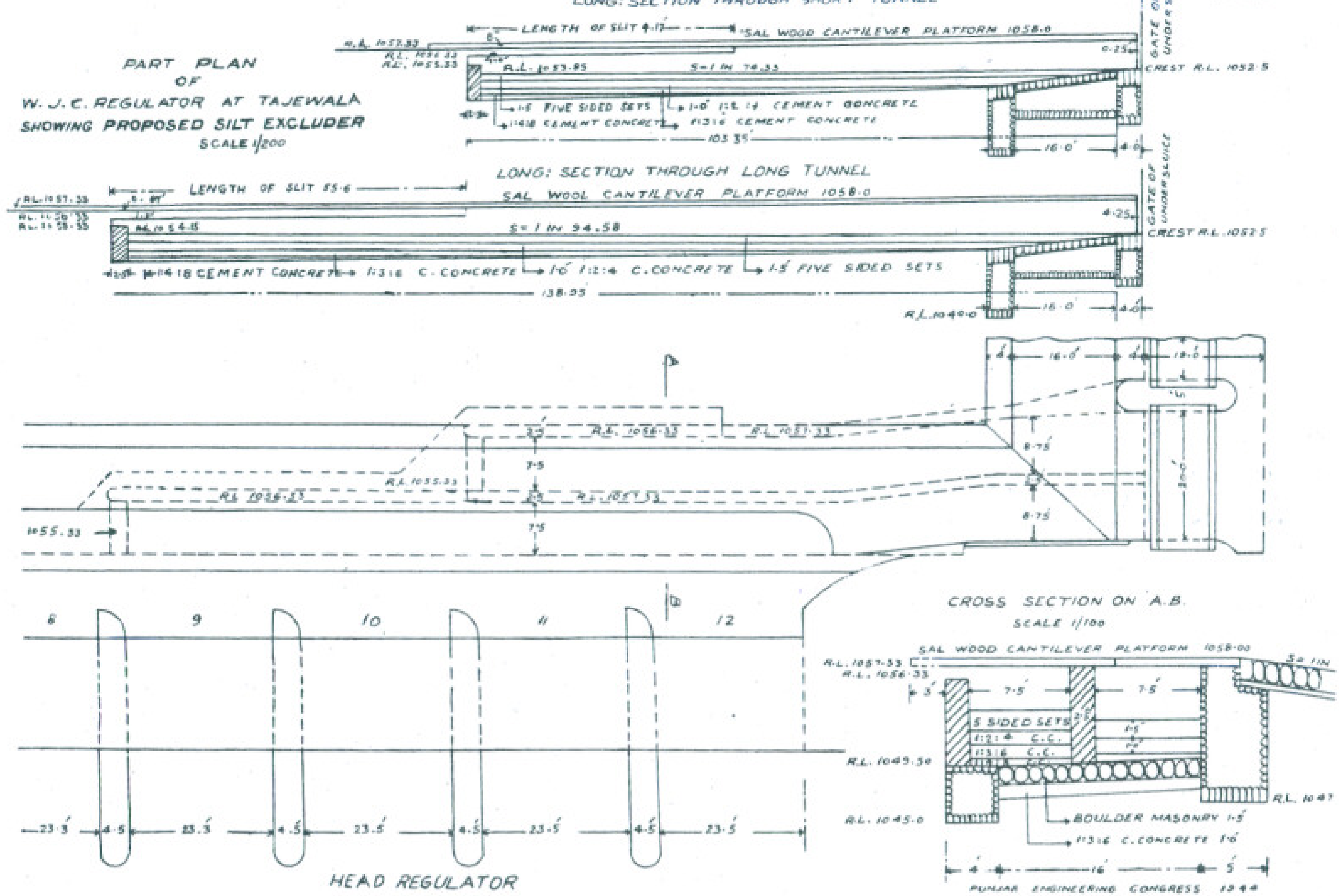
Equivalent discharge.

River 20,000.

Canal 90,000.

No shingle passes over the deflectors into the Pocket. Deflectors highly efficient.

FIG. 17
PAPER NO. 265

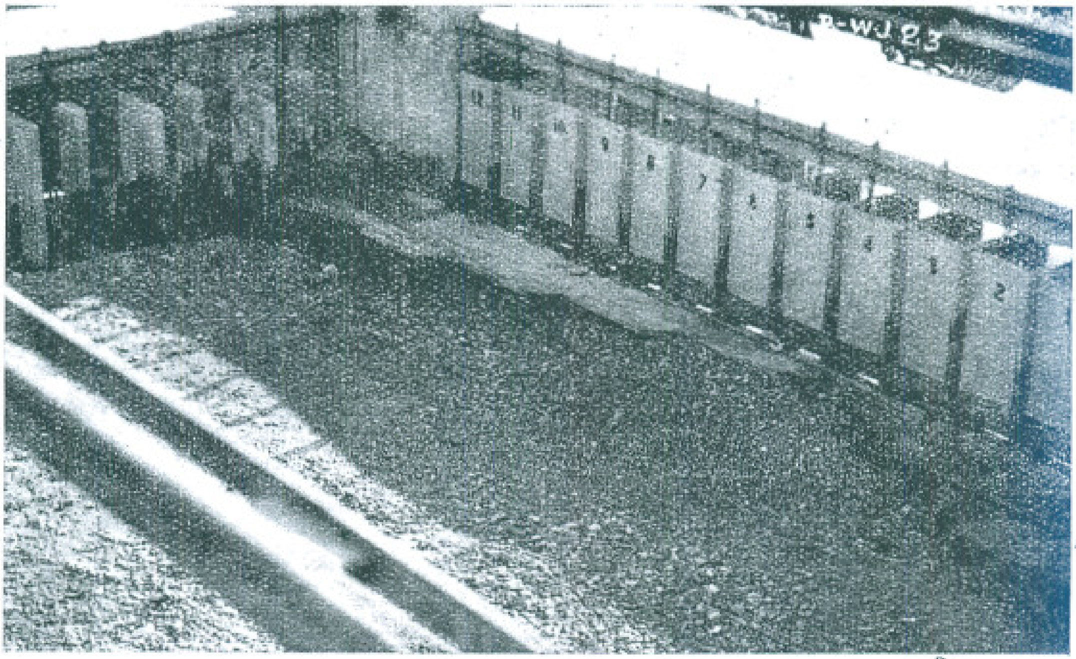


SILT AND SHINGLE EXCLUDERS.

MODEL OF TAJEWALA HEADWORKS.

Khanki type Silt Excluders.

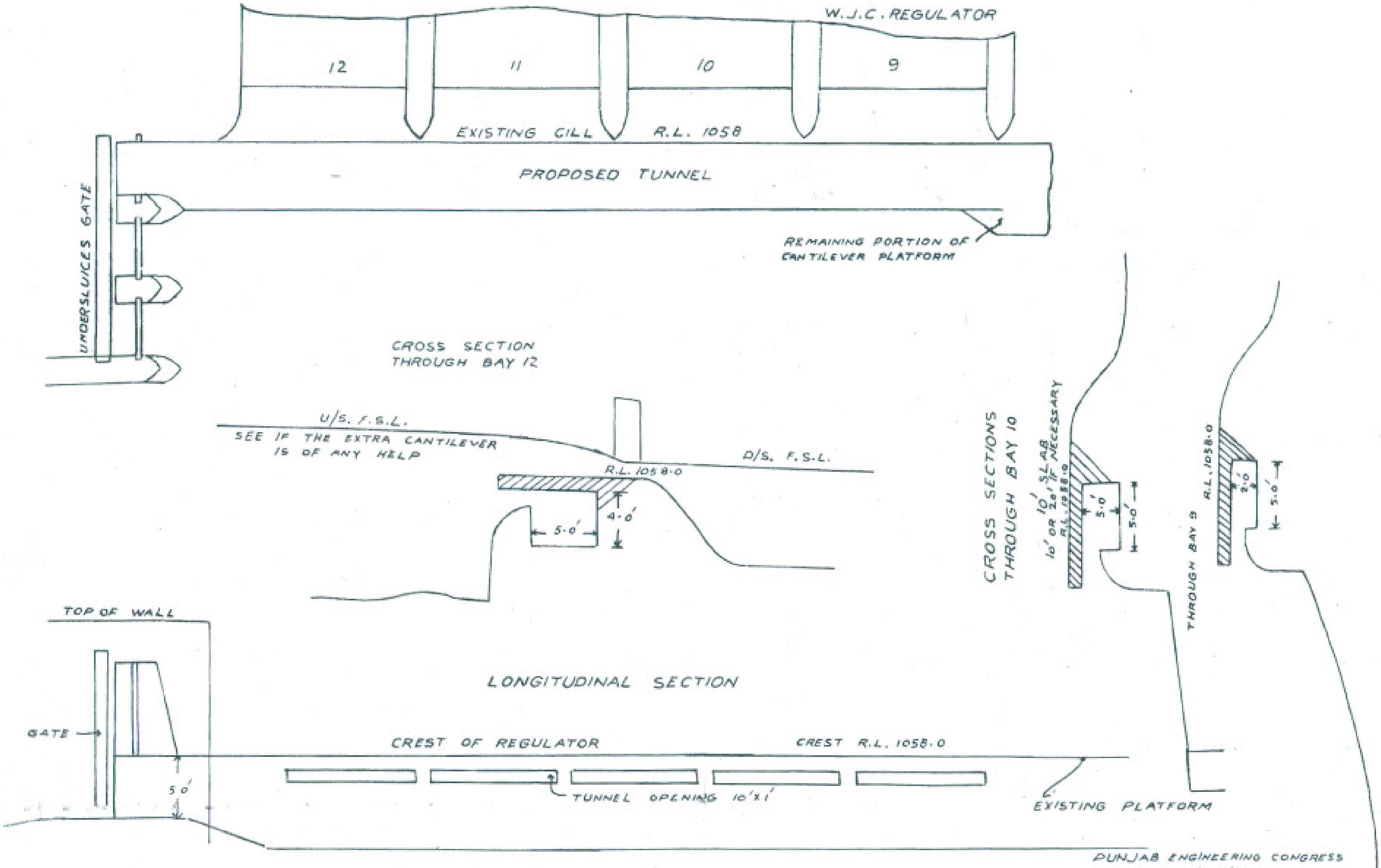
Fig. 17-A.



The model after run.
Photograph indicates shingling up at the mouth.

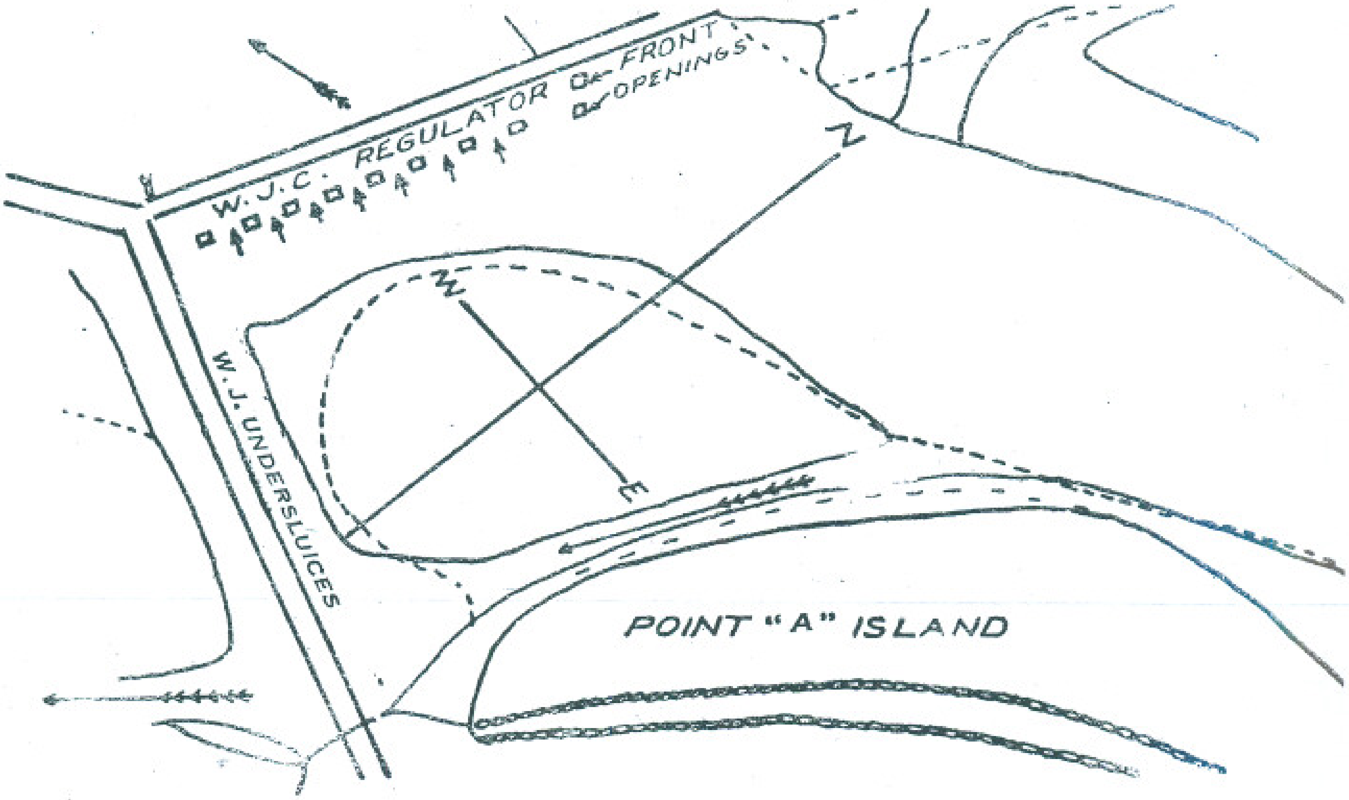
EXPERIMENTAL IMPROVED KHANKI TYPE EJECTOR
FOR 4 BAYS TAKING 500 CUSECS
PROVIDING FOR PUTTING EXTENSION TO 12 BAYS WITH TWO MORE TUNNELS

FIG. 17 B
PAPER NO: 265



PUNJAB ENGINEERING CONGRESS
1944

which moves in that direction gets deposited in front of the openings. The openings from this side, therefore, have been dispensed with in the new design. Straight opening from the north side have only been provided.



(*c*) *Openings near the bed.* The openings close to the crest of the regulator have no advantage. The draw of the canal regulator being greater than the excluder tunnels, shingle goes into the canal rather than into the tunnels through the openings near the top. The openings should, therefore, be as close to the bed as possible.

(*d*) *Horizontal bed and no slope in the tunnels.* Since the velocity of flow in the tunnel is high, there is no necessity of providing a slope in the bed of the tunnel. The bed can be made horizontal.

(*e*) *Bell-mouthing at the entrance.* Bell-mouth shape at the upstream end of the tunnel induces an easy flow of shingle into the tunnel.

Advantage was taken of the existing cantilever platform at the regulator and Two Tunnel type of excluder was developed by incorporating in the design all the essential points mentioned above. The design is illustrated in Fig. 18. It will be seen that there is no other opening into the tunnel excepting at the mouth. The first tunnel is to deal with all the shingle which moves in front of Bays 1—6 and any material which passes beyond the mouth of the first tunnel is to be excluded by the second tunnel. The design was tested on the model and after a continuous run it was shown that the tunnels were very efficient in excluding shingle and silt brought into the pocket by the river. A photograph of the conditions after the run is given in Fig. 18-A.

It will be seen from the photograph that :—

(*i*) The tunnels kept themselves free of any shingle or sand deposit.

(*ii*) No ramp formed in front of the regulator at the level of the crest. The highest ramp level was about 2 ft. lower than the crest of the regulator.

(*iii*) Scour took place round the mouth of the tunnel.

(*iv*) In front of Bay No. 12 the ramp was high.

The efficiency of the Design. The efficiency of the tunnels was calculated on the material collected in the river downstream of the tunnels and in the canal downstream of the regulator and worked out to be 88 per cent. The design proved to be very successful.

Further experiments were made in order to investigate the optimum number, position, width and the height of opening at the mouth of the tunnels.

The optimum number. The optimum number of the tunnels which gave the highest efficiency and did not get choked by continuous running was three, each tunnel covering 3 bays of the regulator from the left side. However, two tunnels, each covering four bays of the regulator, were slightly inferior to the 3-tunnels, but the two tunnels had the advantage of using less discharge. Further improvements introduced made the Two tunnel design highly efficient.

The optimum position. Regarding the optimum position of the mouth of the tunnels it was shown that the most satisfactory results were obtained when the mouths of the tunnels were situated at piers between Bays 8 and 9 and 4 and 5 as shown in Fig. 17.

The optimum width. The optimum width of the main tunnels was found to be 6 ft. and the width at the mouth 12 ft.

The height of opening at the mouth of the tunnels. From the point of view of efficiency the opening near the bed was superior to that along the whole mouth. When the top two feet of the mouth of the tunnels was closed the ramp level in front of the regulator kept much lower than that when the whole mouth was opened. The closing of the top few feet of the mouth had a disadvantage in that once the tunnels are choked, it was difficult to open them. In view of this, full height of the mouth from the bed was adopted.

The details of the test made with the final design are given below :—

Details of the design. Two tunnel.

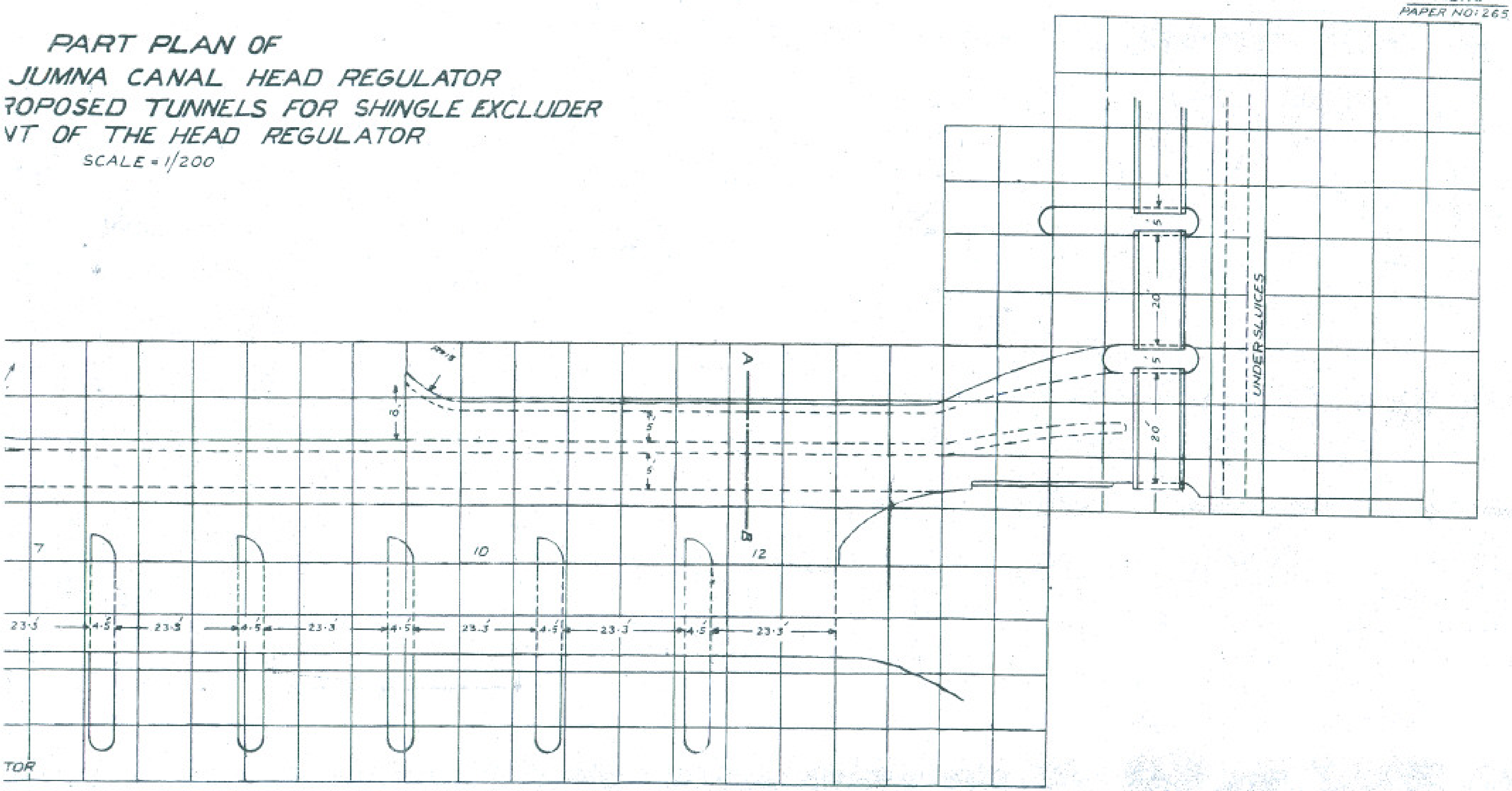
1. First tunnel extended to pier between Bays 4 and 5.

Width of the tunnel	5·7 ft.
Width of the mouth	12 ft.

PAPER NO: 265

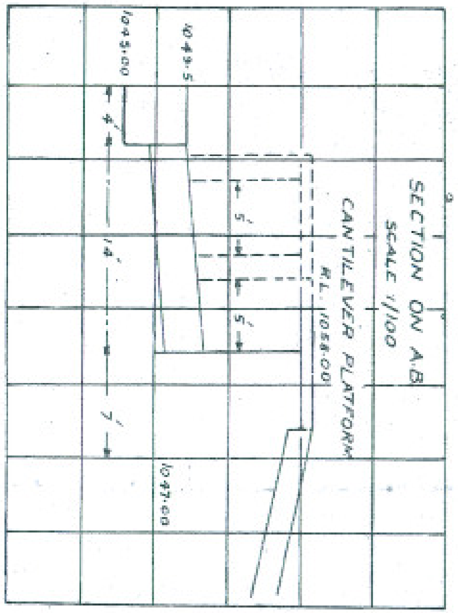
PART PLAN OF
JUMNA CANAL HEAD REGULATOR
ROPOSED TUNNELS FOR SHINGLE EXCLUDER
NT OF THE HEAD REGULATOR

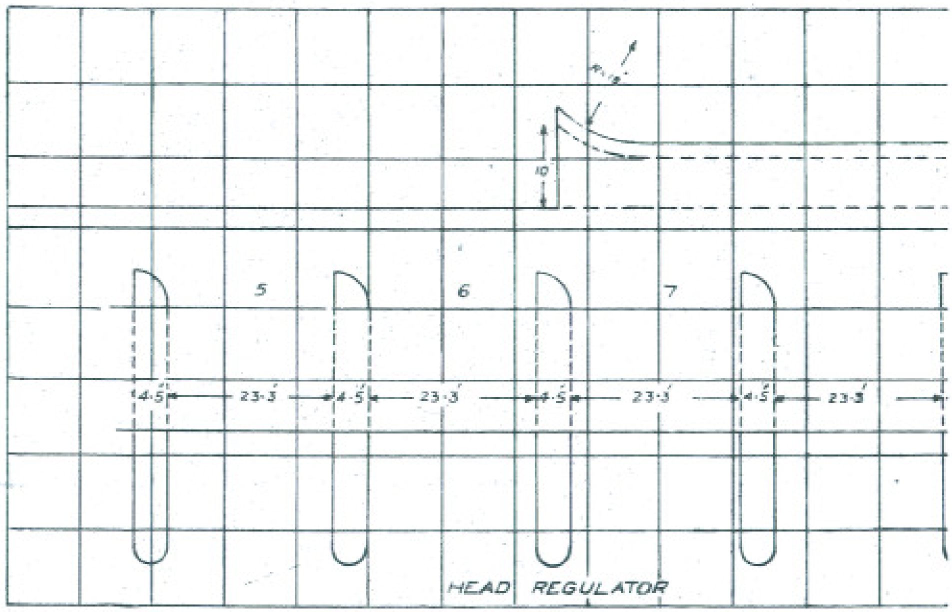
SCALE = 1/200



PART PLAN
WESTERN JUMNA CANAL
SHOWING THE PROPOSED TUNNEL
IN FRONT OF THE HEAD

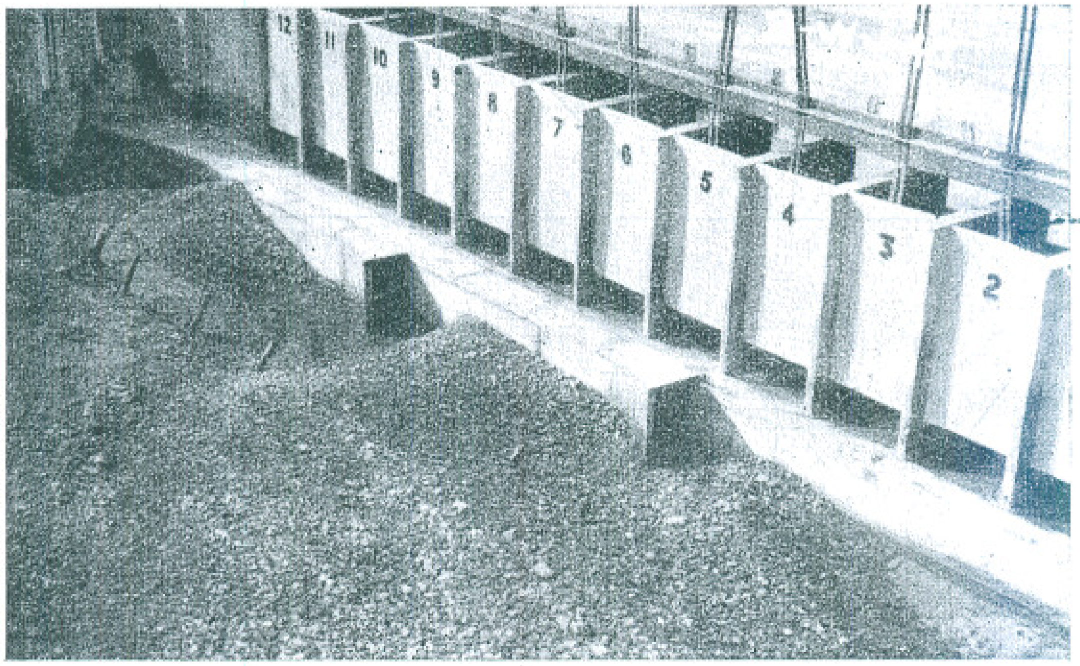
SCALE = 1/200





THE SHINGLE EXCLUDER AT THE HEAD OF THE WESTERN JUMNA CANAL.

Fig. 18-A.



A view of the small scale model of the excluder tunnels and the Tajewala Pocket.

First tunnel — at pier between Bays 4 and 5.

Second tunnel — at pier between Bays 8 and 9.

Ramp formation after 37 hours run. No ramp forms at the level of the crest of the canal regulator.

Efficiency ... ... 97.

2. Second tunnel extended to pier between Bays 8 and 9.

Width of the tunnel	6 ft.
Width of the mouth	12 ft.

Bed Conditions.

Bed in the pocket moulded to Survey of November, 1941.
Floor upstream of Regulator cleared off shingle.

Discharge Conditions.

River discharge in the pocket	= 10,000 cusecs.
Discharge in the canal	= 9,000 cusecs.
Discharge through the tunnels	= 1,000 cusecs.
Period of run	96 hours.

Conditions after the run.

Ramp levels in front of the regulator and bed levels in the pocket.

Bays of the Head Regulator.	Distance from the Head Regulator				Remarks.
	0′	10′	20′	40′	
	R. L.	R. L.	R. L.	R. L.	
Bay No.					
12			10,50·14	10,51·94	
11			51·10	52·48	
10			50·80	52·12	
9			50·56	51·12	
8		10,50·14	51·52	52·42	
7		51·46	52·42	54·46	
6		52·18	52·96	55·30	
5	10,53·38	54·34	54·10	55·78	
4	56·30	56·43	54·70	55·78	
3	53·56	54·70	54·76	56·08	
2	51·28	52·66	53·86	54·46	
1	49·84	50·62	52·60	56·08	

Measurement of the shingle and sand collected.

In the trench downstream of the undersluices	= 3·33 cft.
In the trench downstream of the Regulator	= 0·10 cft.
Efficiency of the tunnels ...	... 97 per cent.

Testing the tunnels by deliberately choking the tunnels to determine if the choked tunnels would open. One of the most important points regarding the design of the tunnels was the case with which the tunnels would open if they became choked at the mouth. There are certain river conditions in which it is not possible to run the tunnels. At the same time the river bed is live and brings detritus. The point for investigation was whether or not the choked tunnels would open up, by opening the gate of the tunnels. For the purposes of this investigation the model was run with the tunnel gate closed and heavy charge of material was added to the river, in order to deliberately choke the tunnels. The tunnels became choked at the mouth only. In the main body of the tunnel there was no great deposit. When the excluder gate was opened the tunnels cleared themselves. However, the opening of the tunnel was facilitated by closing the regulator bay next to the mouth of the tunnel.

Rigid Bed Model. The problem was further examined on a rigid bed model of Tajewala Pocket and the River Jumna up to the Block Bar Spur.

Horizontal :	Model to Prototype	1 to 250.
Vertical :	,, ,, ,,	1 to 25.
Exaggeration :		10.

Fine bajri dyed red was injected into the water upstream of the pocket and the material passing through the tunnels and the bays of the canal regulator was collected and measured.

Efficiency. It was shown from the tests that the tunnels were 99 per cent efficient.

A Large scale part model. A part model of the River Jumna to a very large scale was also examined. The model included the Tajewala pocket, Western Jumna undersluices and the regulator. A length of the river 3,000 ft. upstream of the pocket was only represented. The scales adopted were as follows :—

Horizontal Model to prototype	1 to 10.
Vertical model to prototype	1 to 7.
Exaggeration	1·43.

The river bed on the model was composed of shingle from $\frac{1}{2}''$ to $1\frac{1}{2}''$. The tunnels were constructed according to the final design tested on the first model. A view of the model with the tunnels in position is shown in Fig. 19. Experiments similar to those already carried out were made.

Efficiency. It was shown that the efficiency of tunnels was about 95 per cent. When repeated the efficiency was 97 per cent for shingle. This confirms the conclusions and the indications already obtained.

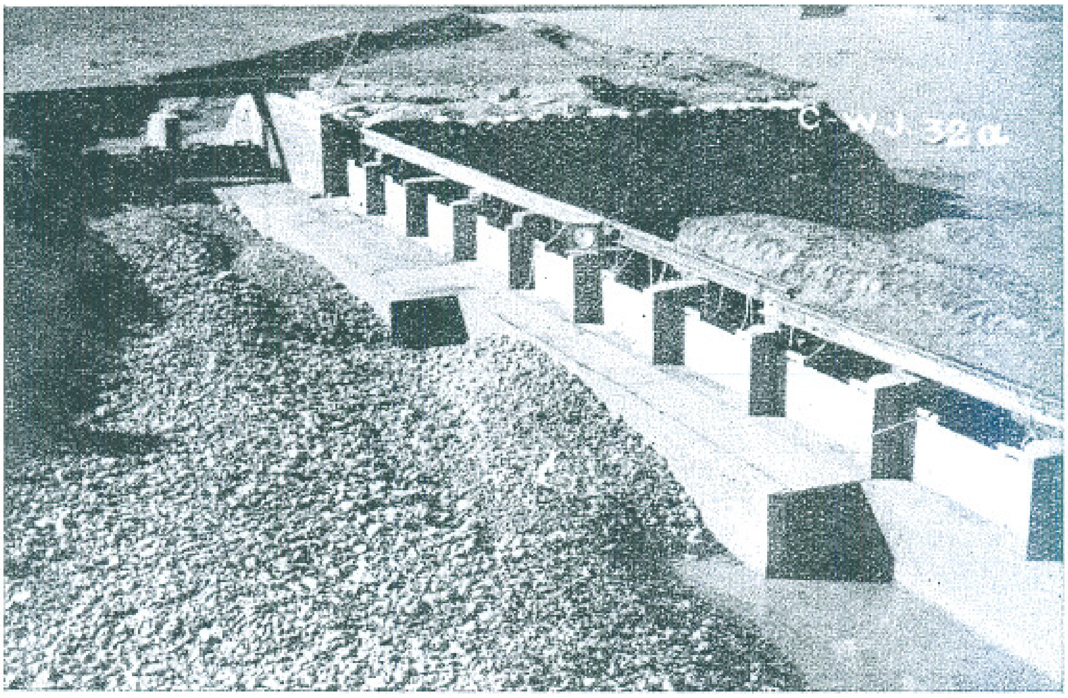
Conclusions. The most satisfactory design for shingle exclusion is two tunnels designed above. The great advantage in this design is simplicity and the small discharge required, *i.e.*, 1/9th of the canal discharge is only used.

The Outfall Channel. The next point in connection with this investigation is the outfall channel downstream of the undersluices below the tunnels for carrying away the materials excluded by the tunnels. If the material excluded by the tunnels is not carried forward and deposits downstream of the tunnels, the tunnels become choked. Detailed experiments were carried out on the most suitable alignment, dimensions and the slope of the channel.

Regarding the alignment of the channel it was shown that the outfall channel constructed must be an independent channel. The water through other bays of the undersluices should not flow into this channel. If the outfall is allowed to be interfered by the flow from other bays, the velocity of flow in the outfall channel upstream of the point, where the tunnel slopes down, starts depositing shingle till the bed rises to the level of the tail end of the tunnel and chokes the tunnels.

THE SHINGLE EXCLUDER AT THE HEAD OF WESTERN JUMNA CANAL.

Fig. 19.



A view of the large scale model of Tajewala Pocket and the excluder tunnels.
Scales adopted :—

Horizontal — Model to prototype	...	1 to 10.
Vertical — Model to prototype	...	1 to 7.
Exaggeration	...	1·43
Area occupied by the model ...	...	300′×150′.

Model discharge corresponding to full supply canal discharge on the prototype ... ... 50 cusecs.

The tunnels remained clear after 96 hours run as shown in the photograph. No shingle enters the canal and no ramp forms at the level of the crest.

Efficiency 97%

It was shown that the most suitable alignment was along the right bank straight to the main River. The dimensions of the channel tested were 20 ft. bed width 1 : 1 side slope and 2·5 ft. in 1,000 ft. bed slope. The bed was plastered.

The construction at Site. The tunnels according to the design obtained on the model have been constructed at site in January 1943. A view of the tunnels is shown in Fig. 20.

The tunnels were tested on the prototype in the monsoon season. No outfall channel had been made. However a temporary channel was excavated from the right to the left side. This worked all right till flow from the remaining bays of the undersluices did not take place. The prototype showed that the tunnels worked satisfactorily. No shingle went into the canal while large quantities of it collected in the river downstream of the excluder bay. Since no outfall channel was made, it was not possible to run the tunnels regularly.

E. A model of the old head regulator, the Main Line up and downstream of the Regulator and the Salampur Feeder.

The Problem. Considerable quantities of shingle and coarse sand have been entering the U. B. D. C, at the new head. It was considered essential to eject the material as far as possible, in the head reach of the canal. The problem, therefore, was to devise methods for the ejection of shingle and coarse sand from the Main Line into the Salampur Feeder at the old head.

Model investigations were carried out in order to determine suitable shingle and sand ejecting devices.

The model.

The Scales of the Model. The following scales were adopted :—

Horizontal	:	Model to prototype	1 to 24
Vertical	:	,, ,, ,,	1 to 8
Exaggeration	:		3.

Besides simple exaggeration no additional tilt was used in the bed.

Items Represented. The following items were represented :

1. The Madhopur Pocket.
2. The Main Line up to the old head and a short distance downstream of the head.
3. The old head regulator and the head regulator of the Salampur Feeder.
4. The Salampur Feeder up to the silt ejector.
5. The ejector and the outfall channel.

A view of the model is shown in Fig. 21.

The Tests. The tests made were :—

1. Full width ejector in the Main Line upstream of the old head.

2. Half width ejector in the Main Line upstream of the old head.

3. Shingle or silt vanes or deflectors in the Main Line upstream of the old head.

The results. The series of investigations carried out showed that the shingle or silt vanes worked very satisfactorily for diverting most of the shingle and coarse sand entered at the new head into the Salampur Feeder. The optimum height and shape of the vanes were determined. The vanes are shown in Fig. 22.

Execution of work at Site. The design of the Silt Vanes as obtained on the model was adopted and the vanes were constructed at site in December 1940.

Observations made on Prototype. Observations were made on the prototype in the summer of 1941 and 1942.

The comparison. An examination of the data collected on the prototype showed :

1. That the working of the vanes on the prototype was similar to that observed on the model.

2. That the whole of the shingle entering the main line at the head was diverted to the Salampur Feeder.

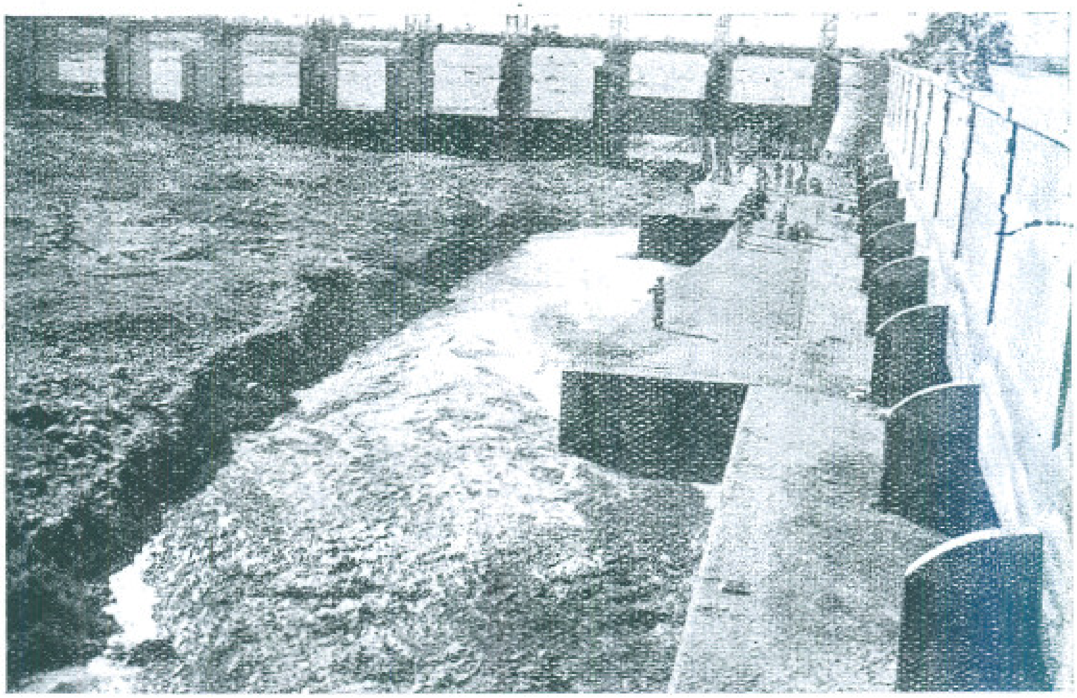
3. That most of the coarse sand was also ejected from the main line into the Salampur Feeder.

A view of the vanes during closure and the material ejected is given in Fig. 23. A detailed comparison for certain items is given below :—

Model Predictions.	*Prototype Observations.*
1. The model experiments showed that between the first vane counting from the right and the right bank a certain amount of deposit would occur.	1. The photographs taken on the prototype show very distinctly the deposit at the place predicted on the model. This is illustrated in Fig. 23.
2. Downstream of the first and the second vanes a deposit would occur sometimes.	2. A deposit downstream of the first two vanes occurs on the prototype, as shown in Fig. 23.
3. The shingle at the third vane counting from the right would travel along the inside of the vane up to the middle of the vane where the curvature is maximum. From this point the shingle and coarse sand moving along the third vane would cross over to the outside of the second vane, as illustrated in Fig. 22.	3. The movement of shingle and coarse sand at the third vane was similar to that predicted on the model.

THE SHINGLE EXCLUDER TUNNELS AT THE HEAD OF THE WESTERN JUMNA CANAL.

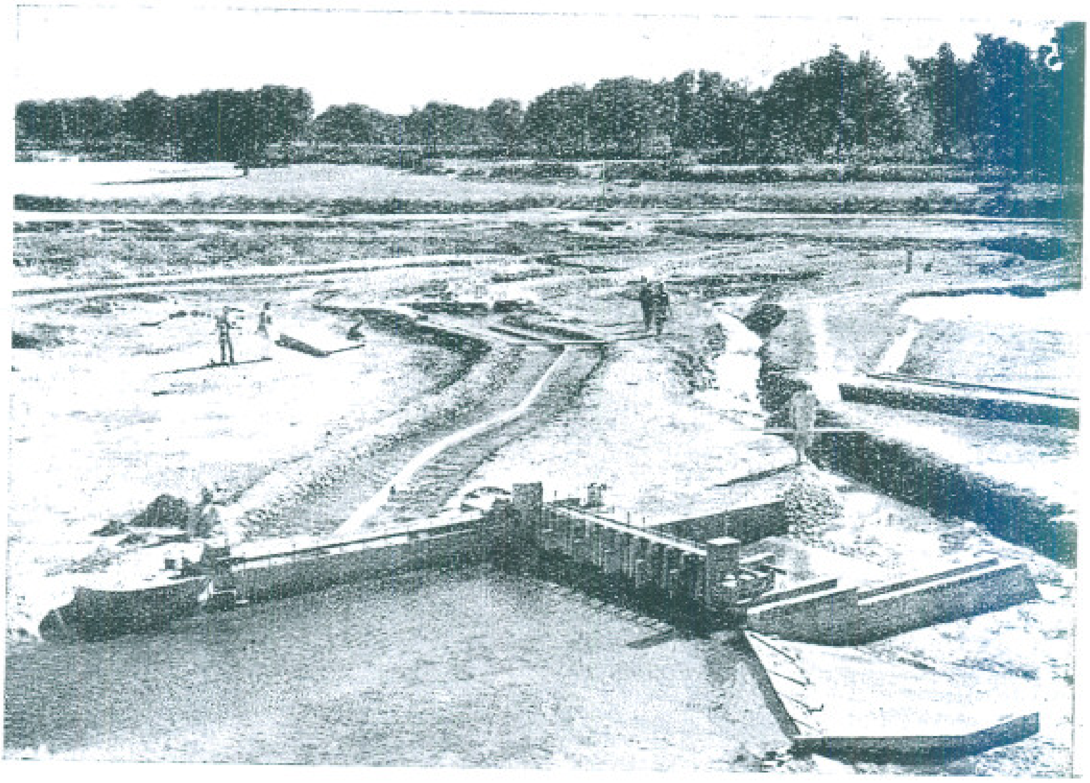
Fig. 20.



This photograph shows the excluder tunnels constructed at site. Water is let in after the canal closure.

THE RIVER RAVI AT MADHOPUR HEADWORKS.

Fig. 21



This photograph shows a view of the Madhopur Pocket Model, the Upper Bari Doab Canal and the Salampur Feeder up to the Silt Ejector.

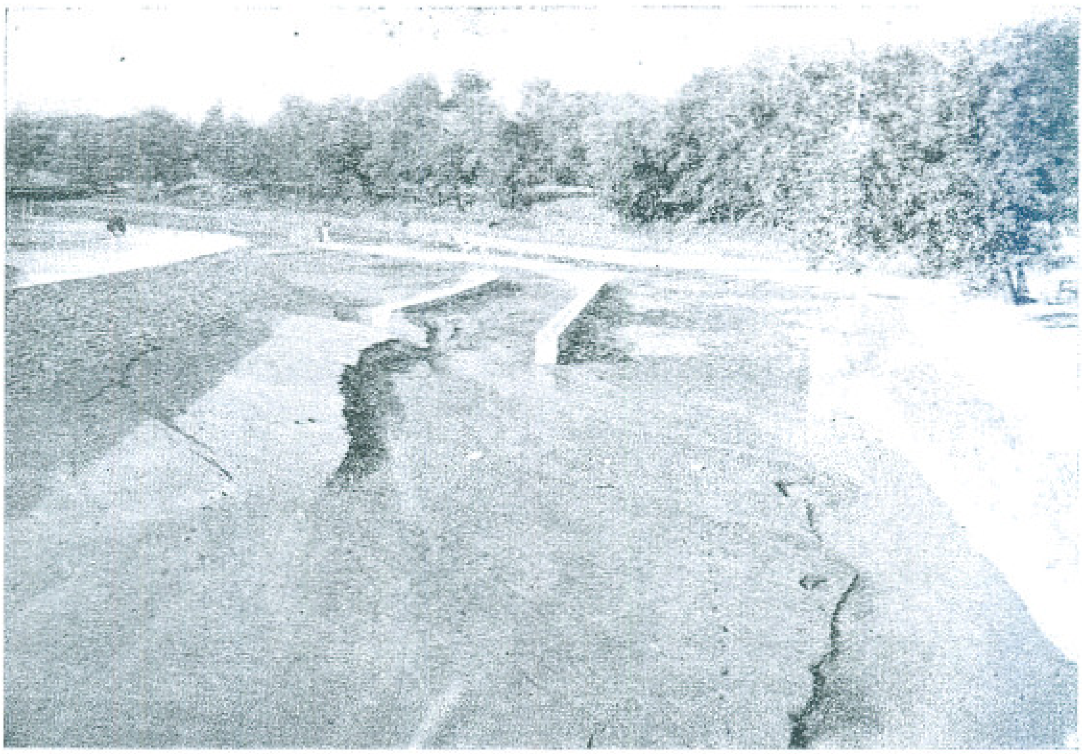
Scales adopted on the model :—

Horizontal	1 to 24.
Vertical	1 to 8.
Exaggeration	3.
Total area occupied by the model	300′×100′.

Model discharge corresponding to 25,000 cusecs on the prototype = 50 cusecs.

INSPECTION ON THE 8TH JULY, 1941, OF THE SILT VANES AT THE OLD HEAD, UPPER BARI DOAB CANAL.

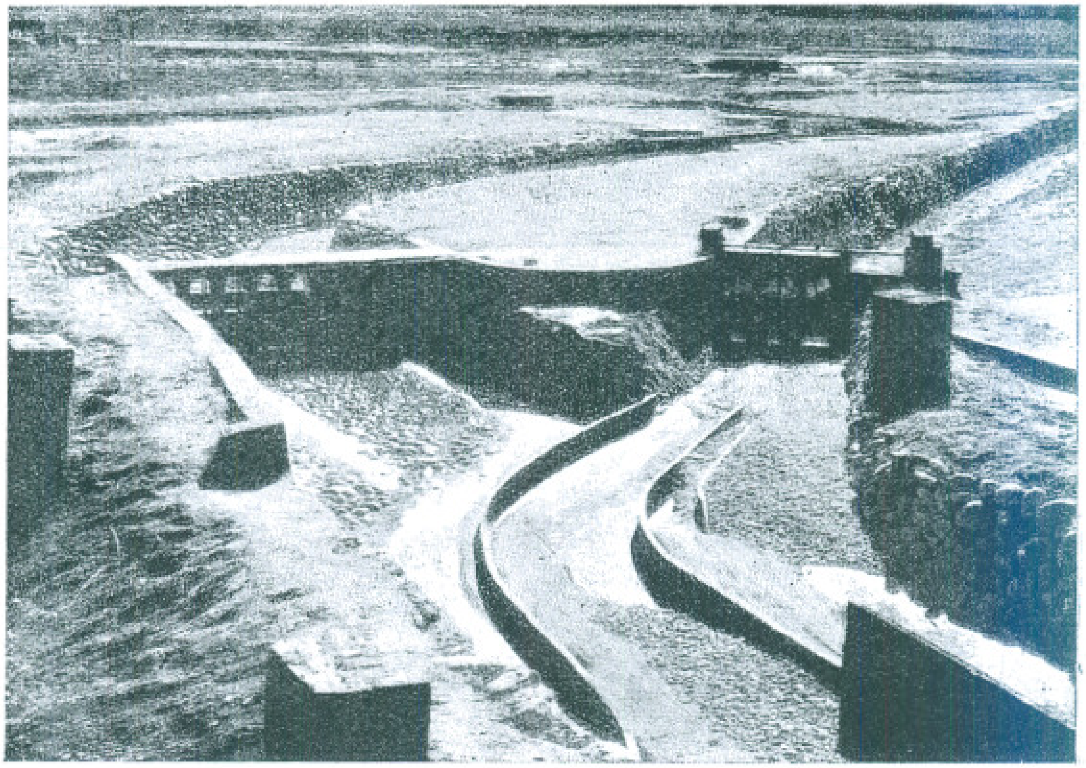
Fig. 23.



Photograph showing a view of the vanes and the channel upstream of the Salampur Head Regulator. It will be seen from this photograph that a large quantity of silt and shingle is ejected by the vanes.

UPPER BARI DOAB CANAL AT THE OLD HEAD.

Fig. 22.



A view of the model of silt vanes as finally proposed for construction.

Model Predictions.	*Prototype Observations.*
4. A certain amount of sand would jump over the third vane near the island. However, the quantity would not be great.	4. Sand jumped over the third vane occasionally near the island.

It has been possible to forecast accurately on the model the behaviour of the vanes regarding the shingle and silt ejection from the Main Line into the Salampur Feeder.

There are several important investigations in hand. It is not possible to give an account of each Fig. 24 shows the recently constructed large scale model of the left pocket of the Suleimanki Headworks.

VII. SOME OF THE IMPORTANT CONCLUSIONS OBTAINED.

From the model investigations carried out at Malikpur the following important conclusions have been derived regarding the working and reliability of different types of models.

The River Models.—1. For the river models the vertical scale should be exaggerated in order to simulate the conditions of flow and bed movement on the prototype. The vertical exaggeration should, however, be not too large, since on the highly exaggerated model it is not possible to reproduce the deep local bed scour and steep bank slopes. An exaggeration of 5 in the vertical scale would give satisfactory results. For models of rivers on shingle bed an exaggeration of 3 works quite satisfactorily.

Experience has shown that for investigation of models of rivers on alluvial bed a horizontal scale of model to prototype of 1 to 100 gives quite a satisfactory results. On such models, problems, of river diversion and river training, can be examined accurately.

2. The Reynold number on river models at low river stages should not be less than 30,000. The number should preferably be higher in order to obtain definite turbulent conditions at all stages on the model.

3. It is preferable to use large scale models with vertical exaggeration and avoid additional tilt.

4. The time scale should be experimentally determined.

5. Since the silt charge considerably influences the bed configuration, the charge required should be correctly determined. It is essential to thoroughly prove the model before testing any schemes.

6. The river gauges on the model can be predicted with great accuracy and also the current directions and velocity. It is possible to forecast bank erosion with reasonable accuracy and also the depth of scour. Thus it is possible to forecast the river behaviour on the model.

7. For models of rigid structures such as weir, canal fall and rapids which involve the formation of a standing wave the vertical and horizontal scales may be the same.

8. No time scale can be fixed for the rigid models. The model is run for different periods and the time of run is determined from the equilibrium conditions of the bed.

9. The co-efficient of discharge of weirs and falls can be accurately determined on a reasonably large scale model.

10. Quantitative measurements regarding depth of scour below masonry works cannot be made. The results obtained are only qualitative and indicate the merits of different designs.

11. On models of masonry structures such as falls, regulators, scour occurs mostly in the first two or three hours of run, later it develops only slightly. The scour curve is of an exponential character. The grade of material used makes only a slight difference in the final depth of scour.

VIII. ECONOMICS OF MODEL EXPERIMENTS.

As a result of the model investigations carried out during the past few years it has been shown that a large saving has been effected. A mention will be made only of certain instances in which estimated figures of original designs and also of the revised estimates as a result of the alteration of design based on the model experiments were available.

1. Thal Project at Kalabagh Headworks. Approximate savings Rs. 4,50,000.

It was originally decided to construct two divide walls one, 1,000 feet long and the other 300 feet long. It was also proposed to construct a silt excluder according to the design adopted at Trimmu. Observations made on the model showed that :

(*i*) Construction of 1,000 feet divide wall did not offer any advantage.

(*ii*) In place of silt excluder according to the design adopted at Trimmu Headworks an ejector of more efficient type could be constructed in the pocket. Both the proposals based on the model were accepted by the Government.

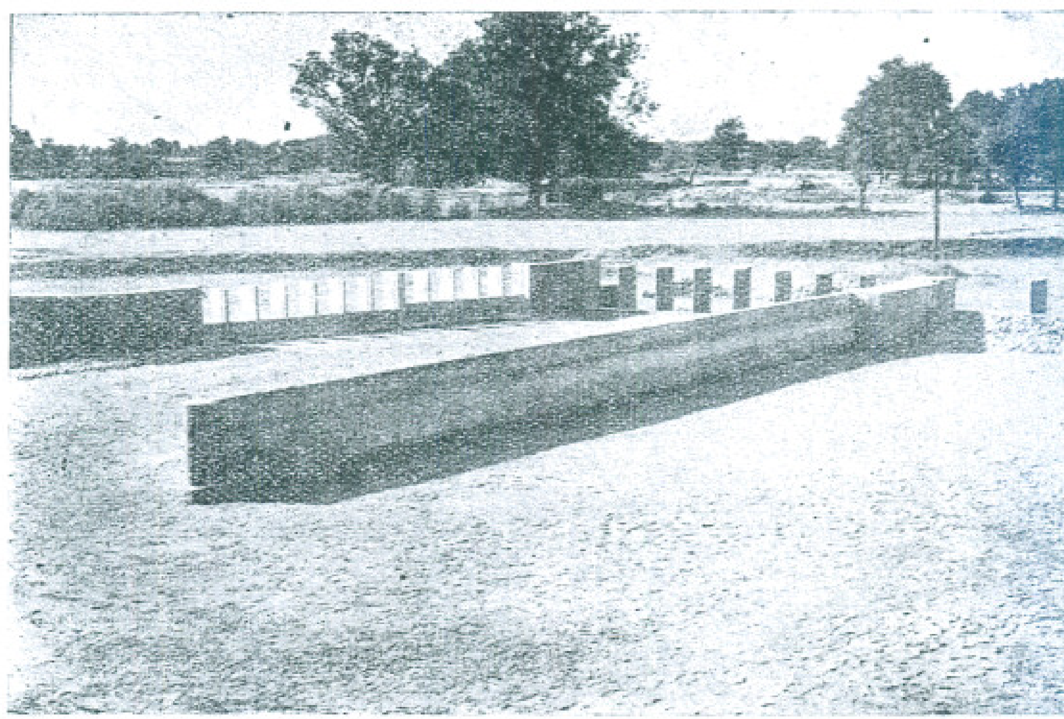
This resulted in a saving of Rs.4,50,000 in the original estimate prepared before carrying out the model experiments. It may be added that the cost of model experiments was insignificant as compared with the savings effected.

2. Diversions of River Sutlej above Suleimanki Headworks. Approximate saving about Rs.2,00,000.

It was originally decided to construct an armoured spur at mile 11 above Suleimanki Headworks to divert the Hasta channel into the main stream. The model experiments showed that an earthen bund with its nose extended to the high land would serve equally well as the armoured spur rather better in certain respects. The proposals were accepted by the Government and the bund was constructed according to the design

RIVER SUTLEJ AT SULEIMANKI HEADWORKS.

Fig. 24.



This photograph shows a view of the model of the left Pocket at Suleimanki Headworks.

Scales adopted :—

Horizontal — Model to prototype	...	1 to 12.
Vertical — Model to prototype	...	1 to 5.
Exaggeration	...	2·4.
Area occupied by the model	...	600′×250′.

Model discharge corresponding to 12,000 cusecs on the prototype = 100 cusecs.

obtained on the model. For the conditions for which it was tested the results obtained were very satisfactory.

3. Shingle Excluder at Tajewala Headworks.

Approximate savings Rs.5,00,000.

It was originally decided to construct a shingle and silt ejector in the head reach of the Western Jumna Canal, Main Line. Model Experiments showed that a simple and efficient type of excluder consisting of only two tunnels could be constructed in the Tajewala Pocket in front of the Head Regulator. This type of the excluder was only of nominal cost.

Only a few of the many instances have been quoted above. There are a number of other cases in which model experiments have proved useful in the design and in reducing the cost of maintenance of Irrigation Works. The system of Staggered Blocks, developed as a result of model studies, for protection below weirs and falls has effected considerable savings in the recurring expenditure on the maintenance of works, such as, Weirs at Panjnad, Khanki, Ferozepore, Rasul, etc., and various falls on the Punjab Canals.

It is economical, therefore, to have a model investigation made before taking the final decision, regarding the design of works.

DISCUSSION

Dr. Uppal while introducing his Paper said that the object of the paper was to give a brief account of the Research Station at Malikpur, the type of work carried out, the technique of experimentation adopted and the results obtained.

The Paper was divided into eight sections. Sections **I, II and III** gave an account of the facilities available. It would be seen from a perusal of this portion that a discharge of 700 cusecs and a slope in the Natural Surface of 50 ft. between the upper and the lower ends of the Station were available. With these facilities, any hydraulic problems could be tested at Malikpur, and at present investigations regarding outlets, canal falls, regulators, level crossings, silt excluders, silt ejectors, weir design, weir co-efficients, river regulation, river diversion and training were being carried out. It was proposed to test models of dams, etc., in the near future.

The Station is fitted with the latest precision instruments.

In Section V, a brief account was given of the methods of construction of model and technique of experimentation. The methods adopted had been developed independently at Malikpur. These methods were in no way inferior to any one of those adopted in other parts of the world. In certain aspects they were definitely better. In this connection reference might be made to the Manual of Engineering Practice No. 25 on Hydraulic Models, prepared by the Committee of Hydraulic Division of the American Society of Civil Engineers. This Paper was received by the author only a couple of months back. The methods advocated in this Manual were similar to those adopted at Malikpur.

In Section VI, an account of some of the investigations carried out and verification of the model results from observations on the prototype were given. Regarding the verification of the model results from observations on the prototype, it might be pointed out that it is not possible to expect cent per cent agreement between the model and the prototype. There are types of models which give quantitative agreement with the prototype results. There are other types of models from which we can expect only qualitative agreement and still there are others which can not give any indication. This all depends upon the fact how far the model behaviour is similar to the prototype.

There are three types of similarity :

(*i*) Geometrical similarity.

(*ii*) Kinematic similarity.

(*iii*) Dynamic.

In the geometrical similarity, the ratios of all homologous are equal. This is the similarity of the form only.

In the kinematic similarity the ratios of the velocity of various homologous particles involved in the motion occurrences are equal. This is the similarity of motion.

In the dynamic similarity the ratios of the masses and forces of various homologous objects involved in the motion occurrence are equal. This is the similarity of masses and forces. Complete dynamic similarity is an ideal, rarely attained in any model.

The flow-characteristic would be similar, however, if the fluid properties are such that the gravitational, viscous, capillary and elastic forces bear the required relationship between the model and the prototype.

In fluid motion phenomenon, forces and physical properties influencing motion occurrences could be expressed as :

(*i*) Gravitational force, *i.e.*, Froude Number $= v^2/gR$.

(*ii*) Viscosity by Reynolds Number $= \dfrac{VR}{\gamma}$

(*iii*) Surface tension by Weber's Number $= \dfrac{Pv^2R}{S}$

(*iv*) Elasticity by Cauchy Number $= \dfrac{P\,v^2}{E}$

If the occurrence was such that several equally important forces took part in the action, the problem of attaining similitude becomes very difficult. For all practical purposes, the Cauchy Number of the elasticity might be ignored in the general model study referred to in the paper since both the model and the prototype are assumed to be rigid. Similarly the forces of capillarity could also be ignored when the model is fairly large. This leaves us with Froude and Reynolds Numbers, *i.e.*, with gravitational and the viscous force. Both the criteria could be satisfied, if a different model fluid is used. In practice, however, water is used on the models. Satisfactory experiments could be made when one of the two, gravitational or the viscous force is predominant. The concern of the experimenter should be to take full account of the force which is considered dominant. The neglect of other forces would introduce only a slight inaccuracy in the final results. The efforts should be made, therefore, to choose scales, such that the effect of the non-dominant forces is negligible. This is the essence of model experimentation. Quoting an instance, in any experiment on the design of the bridge pier, the gravitational force would be the predominating force, and on a large scale model, the effect of viscosity and surface tension would be negligible.

A mention, however, may be made about the force of viscosity or the Reynold Numbers. It is not possible, to have the same Reynold Numbers on the model as on the prototype and it is shown that it is not necessary either to have the same number. If the model is large and the flow turbulent, the Reynold Numbers are fairly high. Under conditions of fully developed turbulent flow in a model or prototype, the friction co-efficient is constant for any one roughness value and independent of viscosity. What should be aimed at is to have a fully developed turbulent flow on the model.

On all the river models at Malikpur, the Reynold Number exceeded 1,00,000.

Another important point is the length of entrance and exit. The entrance and exit should be very large, since they influence considerably the conditions of flow at the point of investigation.

It is easy to predict on the model the river behaviour for a period of two to three years, but it is difficult to forecast conditions of flow 10 or 20 years ahead due to the river changes occurring upstream of the point from where the model had been represented.

Generally it takes about a year to carry out a river investigation. Investigations of models of rigid structures, such as bridges, falls, weirs, etc., take much less time.

Since the paper was written, another important investigation has been completed. A study of a model of the River Sutlej above Islam Headworks was made. The River Sutlej above Islam Headworks had been meandering between the left and the right retired embankments. Since the construction of the new 'T' Head Spur, the river at mile 6 above the Islam Weir moved towards the left, the erosion of the left bank became heavy and the retired embankment at that place was threatened two years after the construction of the spur. The problem for investigation was whether the left retired embankment at R. D. 30,000 would be attacked or not, and what were the most suitable methods of protection of the embankment. In order to study this, a model of the River Sutlej for a length of 10 miles above Islam Headworks was made to the following scales :—

Horizontal	Model to prototype ...	1—100
Vertical	Do ...	1—20
Exaggeration	... ...	5

Item reproduced. The Headworks, the training works and all the retired embankments were reproduced on the model.

After proving the model, tests were made and it was shown that in discharges upto 1,00,000 cusecs, the left bank at mile 6 would be completely washed away and the left retired embankment would be attacked.

However, in discharges above 1,50,000 cusecs, a cut-off would occur at mile 7, as shown in Fig. 1, and the whole of the area in front of the retired embankment which had been attacked would commence silting up.

Observations made on the prototype confirmed all the indications obtained on the model. The cut-off occurred at exactly the same place at which it was indicated on the model.

As a result of this cut-off, the river began to erode the right bank at mile 11. The retired embankments at this place was threatened. There are two retired embankments, the Right Retired Embankment and the abandoned Right Retired Embankment. It was required to determine the methods of protection to be adopted at this place. For this purpose, the model of the River Sutlej above Islam was extended upstream for a length of 5 miles.

It was shown on the model that the abandoned Right Retired Embankment would be attacked first at a point opposite R. D. 55,000 of R. R. E. and later erosion of the embankment would extend downstream. At certain portion the embankment would be washed away. Behind the retired embankment, the right bank would be washed away for a depth of 600 ft.

However, it was shown from the model that it is not necessary to construct any protective works, since once the abandoned Right Retired Embankment was breached, water would spill over the area between the abandoned and the Right Retired Embankment and cause silting up. What actually required was to construct an inlet and an outlet for the area between the two retired embankments.

Observations on the prototype justified the conclusions obtained on the model. It will, thus be seen that model study is a valuable guide in making decisions regarding the river training works.

Another important observation made was about the shingle excluder, referred to on page 32, constructed in front of the Western Jumna Head Regulator at Tajewala Headworks. Observations were made by the Local Officers during the Monsoon of 1943. The shingle excluder was first opened on 15th June, 1943, when the river conditions were as given below :

Ponta Gauge	...	19·4
River discharge above Tajewala works	...	8994 Cs.
River discharge below Tajewala works	...	2960 Cs.
Western Jumna Canal discharge ...	...	6034 Cs.
Pond Level	R. L.	1061·1
Water level downstream of W. J. Sluices	R. L.	1054·2
Tunnel gate opening	...	4·5 ft.
Centre level of tunnel	R. L.	1054·9
Approximate discharge through tunnels	...	1023 Cs.

The excluder was again worked on 16th to 18th of June and from 3rd to 19th of July. A temporary outfall channel was constructed downstream of the excluder. It was shown from these observations that when the excluder tunnel was working, not a single particle of shingle entered the canal. This is very important, since it confirmed the model results.

It was also shown that the tunnels, if they became choked, would open up when a head of 5 to 6 ft. was applied. These observations again showed that the prototype results agreed very closely with those predicted on the model.

Mr. Khanna said that he just wanted to say a few words regarding spurs on River Beas that were constructed by him according to the data supplied by the model experiments done at Malikpur.

The experiments were concluded in the month of January 1940 and the spurs were completed before the flood season, the same year. Construction had, therefore, followed the experiments very closely without allowing the river conditions to be altered by a flood season. The results actually obtained were, therefore, particularly important with a view to study relationship between the model and the prototype.

The river conditions as actually obtained in this reach are shown on this plan which also shows the line of maximum erosion as predicted by experiments. River edge after the flood season of 1940 is shown green dotted and that after the flood season of 1941 is shown in sienna—the erosion line as predicted by model experiment is shown in blue.

In broad outlines the river did follow the erosion line as predicted, though the differences in the amount of maximum depth of erosion as measured from the chord joining the ends of spurs were considerable. Between Spurs No. 1 and 2 this measurement came to 713 feet against 475 feet predicted and between Spurs No. 2 and 3 it came to 963 against 690 ft. predicted.

II. It was at the end of August, 1942, when he was on 10 days casual leave that he got a telegram from his Superintending Engineer, asking him to come back at once and proceed straight to Dasuya, as desired by Chief Engineer, to see if something could be done to save the spurs that were under a very severe attack of the river. He returned immediately but before he could reach the spurs the worst had happened. He met both the Executive Engineer and the S. D. O. in charge and went over the spurs with them. The river had breached through the shank of Spur No. (2) as shown in red on this plan.

Now this is rather interesting. The shank had been breached and nearly half of its length had been washed away but the spur head itself was standing like an island in the middle of the river. He thought it was a very good testimony of the quality of work done.

The question naturally arises as to why should the river have tried to break through the shank when it is supposed to be tied to the spur heads. The reply is simple. The river was allowed to take a sweep which was too big for the spurs to look after. This is because the spurs were spaced too far apart. This caused parallel flow to set up along the shank of Spur No. (2), which resulted in the river breaking through the shank. To his mind it was here that the experiments failed them.

It was not expected of the experiments to reproduce the results correct to the last foot when they were handling big river discharges but the experiments should have shown that it was positively risky to space the spurs so far apart. On the other hand the maximum extent of erosion predicted by the experiments had been exceeded even without the record flood passing down the river.

It was mentioned in the Paper that the maximum flood in 1942 at Dera Gopipur was 3,84,000 cusecs against 2,84,000 cusecs ever recroded before. He had got there R.Ls. of maximum flood levels at Spur No. (2) for the years 1941 and 1942. These were :

		Year 1941	*Year 1942*
At Spur No. 2 upstream	...	785·40	787·60
At Spur No. 2 downstream	...	784·90	786·30
R. L. of Top of Spur No. 2	=	792·06.	...

Maximum flood levels in 1942 were actually about 2·0 ft. higher than those in 1941 and at the time the maximum flood was passing in 1942 ; there was still a free board of 4½ ft. below the top of the spur.

He said that he might make that clear that he did not say for a moment that the model experiments were not useful. In the particular case under examination the model experiments helped them to fix the lengths of the shanks of the spurs and also the width of aprons by giving the depths of the maximum scour. It was, however, not correct to say that the models would produce the actual conditions to the last foot and it was in this respect that the results had to be used with caution.

1. **Mr. Hamid** said : That the Malikpur Testing Station has developed remarkably rapidly, starting practically from 1936 and its present potentialities could be judged by the following figures :—

	At Malikpur	*At other Stations.*
Discharge available for experiments.	700 Cs.	100 cusecs or so.
Land available for experiments	100 acres.	Others only small areas. Poona only 8 acres.

Similarly the Hydraulic Laboratory of the Punjab Irrigation Research Institute had 13 cusecs available for experiments against 2 cusecs at the maximum at other stations. But long lengths of rivers had to be reproduced for experiments for training works which space did not permit in a laboratory ; also flow conditions for heavy material transported by rivers could not be accurately reproduced on small scale models in laboratories ; hence the great advantage of a station like Malikpur where problems of any magnitude could be tackled as also a number of experiments could be carried out at the same time which help progress.

2. That the testing station could hardly be in better hands ; the guidance was available under the present regime from the highly placed and the experiments of the Irrigation Branch could hardly ever be surpassed. But the testing station was not their monopoly alone. Ideas of

all officers who took interest in research were sympathetically examined and tested where considered promising.

3. That he had been associated in a direct or indirect way with the Research Laboratory and the Testing Station from 1936. He was in charge of the Islam Weir and supplied data for experiments for a cut, spurs and an Island for the Islam Headworks and watched the experiments with interest. Experiments for the Jaba Level Crossing ; staggered blocks and other similar works and devices in the laboratory were interesting. In 1941 he was directly concerned with the experiments for the closing of the Hasta Creek upstream of the Suleimanki Headworks of which a reference was made later on. When in charge of the Majitha Division in 1942, he was directly concerned with the experiments for a silt excluder at Aliwal.

4. That the problem of the Hasta Creek might be mentioned with advantage. Matters came to a head in January 1941 just when he took over charge of the West Section as Under Secretary. The higher authorities wanted to protect the left marginal bund by means of an armoured spur. Dr. Uppal had an idea that an ordinary earthen groyne could serve the purpose. If the groyne failed the risk would be too great as the marginal bund might be eroded the same year with the consequent danger of outflanking of the weir. Dr. Uppal discussed the problem with him. He, having had some experience of inundation canals as Under Secretary, saw that Dr. Uppal's proposal was sound. A discussion was held. The late R. B. Ganpat Rai who was working as Officer on Special Duty in charge of the West Administration, was strongly opposed to Dr. Uppal's proposal. Valuable time might be wasted in model experiments which would make construction of an armoured spur impossible that year. However, Dr. Uppal's persistance and his support won the day and orders were given by Mr. Lyster, the then Chief Engineer, for carrying out the experiments which were completed in record time and testified to the soundness of Dr. Uppal's proposal. A groyne was built and proved satisfactory as anticipated. This saved Rs. 2 lakhs. Without a testing station where experiments could be carried out on a large scale and promptly the Chief Engineer could not possibly have taken the responsibility of approving of a groyne in preference to an armoured spur under these circumstances.

5. That experiments were carried out for a silt excluder at Aliwal, the head of the Lahore Branch and Main Branch Lower of the U. B. D. C. The Jaba type was tested. The local officers' suggestions were tried out and a modified design was obtained with an efficiency of 85%.

6. That co-operation of local officers was very necessary for getting good results. Experiments were to be carried out for preventing scour downstream of a fall on the Mailsi Canal. The fall existed at a site where the centre lines of the upstream and downstream reaches met at an angle and no curve had been provided in the canal. The upstream

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4. That the problem of the Hasta Creek might be mentioned with advantage. Matters came to a head in January 1941 just when he took over charge of the West Section as Under Secretary. The higher authorities wanted to protect the left marginal bund by means of an armoured spur. Dr. Uppal had an idea that an ordinary earthen groyne could serve the purpose. If the groyne failed the risk would be too great as the marginal bund might be eroded the same year with the consequent danger of outflanking of the weir. Dr. Uppal discussed the problem with him. He, having had some experience of inundation canals as Under Secretary, saw that Dr. Uppal's proposal was sound. A discussion was held. The late R. B. Ganpat Rai who was working as Officer on Special Duty in charge of the West Administration, was strongly opposed to Dr. Uppal's proposal. Valuable time might be wasted in model experiments which would make construction of an armoured spur impossible that year. However, Dr. Uppal's persistance and his support won the day and orders were given by Mr. Lyster, the then Chief Engineer, for carrying out the experiments which were completed in record time and testified to the soundness of Dr. Uppal's proposal. A groyne was built and proved satisfactory as anticipated. This saved Rs. 2 lakhs. Without a testing station where experiments could be carried out on a large scale and promptly the Chief Engineer could not possibly have taken the responsibility of approving of a groyne in preference to an armoured spur under these circumstances.

5. That experiments were carried out for a silt excluder at Aliwal, the head of the Lahore Branch and Main Branch Lower of the U. B. D. C. The Jaba type was tested. The local officers' suggestions were tried out and a modified design was obtained with an efficiency of 85%.

6. That co-operation of local officers was very necessary for getting good results. Experiments were to be carried out for preventing scour downstream of a fall on the Mailsi Canal. The fall existed at a site where the centre lines of the upstream and downstream reaches met at an angle and no curve had been provided in the canal. The upstream

approach of water to the fall was oblique. The local officers, when supplying the data, did not show the angle of upstream approach. The results with such data would not have been true. The error was, however, rectified in time as the site was known to him. If officers wanted good results they had got to study the site and data intelligently and keenly.

7. This Testing Station should not monopolise the research work to the utter exclusion of other officers. Some officers felt that they had no latitude for testing their individual ideas on various matters. It would not be possible for the Research Institute to sift and test the ideas of all officers. He suggested that the Chief Engineers should remove this impression and encourage research work in Divisions and sanction funds where they were satisfied that the local officers had the capacity for such work and would not neglect their proper work. Sometimes important things worked out while fiddling with small matters. A few very small testing stations here and there would not be wasteful expense. He recently found at a small apology for a Testing Station at Aliwal that even if minimum modular head was available, an outlet did not draw its correct discharge if the bed level of the watercourse was higher than the crest level of the outlet beyond a certain limit. More detailed experiments were required on this matter.

8. That the silt excluder proposed for the W. J. C. at head required some remarks. It was well known that where the velocity of the current was high the top filaments were not drawn into an offtaking channel and its total discharge was drawn from the bottom filaments of the parent channel from a distorted semi-elliptical zone, the path of flow of the drawn-in water being curved and nearly at right angles to the forward motion of the water in the parent channel. Obviously shingle would be drawn into the offtaking channel along the same path, *i. e.*, in a direction transverse to the current direction of the parent channel. Having openings for the silt excluding tunnels facing the direction of flow of the parent channel was, therefore, not a rational design ; the openings should be from the sides. The author of the paper stated that openings on the sides were tested and found less efficient but these openings were kept too high and should have been nearer the bottom. A look at the photographs attached by Dr. Uppal showed that a ramp formed, but that sloped down away from the Head Regulator Crest and not towards the Head Regulator as shown by Dr. Uppal's figures. This further supported his suggestion for side openings.

Further, with side openings, there should be a larger number of smaller section tunnels as in the Jaba type.

It would help in understanding the real flow and shingle-draw conditions if the Research Officer tried out a model as suggested above.

Mr. Vadera said that the shingle excluder at the head of the Western Jumna Canal was built in the winter closure of 1943 in accordance with the design elaborated at the Malikpur Research Station, a description of which appears at pages 32—36 of the paper, along with diagrams and photographs.

2. The two tunnels of the shingle excluder were constructed very quickly. The total cost of the work was in the neighbourhood of one lakh of rupees, and was completed within a period of about 2½ weeks. This was possible only on account of the well-thought out plan of construction, and he must say the work was executed with remarkable speed and efficiency even for the modern ideas of speed, considering that the space available for work operations was very limited indeed.

The shingle excluder started working on the 4th of July 1943 and worked almost continuously for about six days, *i.e.*, upto 10th July, when a flood of 150,000 cusecs changed the hydraulic conditions of the tunnels. The working head of the tunnels was considerably reduced and the roof of the shorter of the two tunnels was also damaged during the flood. This tunnel went out of action by getting choked up while the longer tunnel continued functioning up to the 19th of July. On the 23rd of July, the larger tunnel was also found to be choked up, but by opening bay No. 1 of the undersluices, a part of the shingle deposit which choked up the tunnel was washed out, with the result that the tunnel again started functioning although only partially. This longer tunnel also got finally choked up on the 25th of July and although the pond level was raised so high as to create a working head of 5 ft., the tunnels remained choked, and never functioned afterwards.

3. In this connection the following observations were made :—

(*a*) So long as the shingle excluder tunnels were functioning, no shingle entered the canal, which was an extremely satisfactory feature of the excluder, and bore out the results obtained by model experiments on the tunnels.

(*b*) He was of opinion that the shingle excluder got choked up on account of the unsatisfactory outfall channel. With a proper outfall channel, which would not be influenced by river levels downstream of the undersluices and which would be a properly lined and graded channel, it should be possible to run the shingle excluder successfully. Experiments to evolve a suitable outfall channel for the shingle excluder were being conducted at the Research Station, Malikpur and it was hoped that at least a part of the outfall channel would soon be constructed.

(*c*) The bell-mouthing at the entrance of tunnels was in a way detrimental to their functioning, because the section at the entrance was considerably larger than the tunnel section with the result that if any submerged jungle rolling along the bed which passed through the bell mouthed entrance got stuck in the channel, thus throwing them out of action. It was, therefore, suggested that the bell mouthing might be dispensed with if it did not detract materially from the efficiency of the tunnels.

4. There was no doubt that the design of the tunnels evolved at the Research Station, Malikpur was suitable for the Hydraulic conditions obtaining at Tajewala, and for the exclusion of heavy grades of shingle, but for proper functioning of the excluder it had to be combined with a suitable outfall channel.

Mr. Chaturvedi congratulated Dr. Uppal for writing such a splendid paper on the Malikpur Research Station where so much useful model work was being carried on by him year after year. He had nothing to say about Chapters I to IV of this note, except expressing his appreciation of the vivid description given therein of the details which would prove of help in the organization and installation of any such station which an engineer might be called upon to do elsewhere.

He said that he would, however, like to observe about the 'Methods of Investigation' given in Chapter V, that a little greater detail would have gone a long way towards increasing the utility of this paper. The success of model experiments depends upon design of the model, which in turn depends upon the proper scales. While mentioning the vertical scales, Dr. Uppal quoted four mathematical formulae, *i.e.*, Manning's, Kutter's, Winkel's and Lacey's, but it was not given which one gave the best results. With the vast experience of model work obtained at this Research Station, such a point might have been further elaborated.

As regards the discharge scales, it was mentioned (page 11) that 'the actual discharge of the prototype divided by the model discharge which reproduces the gauges of the prototype gives the discharge scale.' Earlier while determining the vertical scale of models for rivers on shingle bed, discharge was adopted as one corresponding to which bed movement occurred at site. This sounded to him contradictory, through it might not be so to Dr. Uppal. It was suggested there that the discharge scale might be connected to the horizontal scale by the relation derived by Inglis, *viz*., Me d/Q where Me was meander length and the length scale connected to the vertical scale by the best of the four formulae quoted earlier.

Referring to silt charge, Dr. Uppal mentioned, 'the quantity of material which maintains the bed equilibrium is the correct charge to be used on the model.' In other words a sort of Lacey regime was required to be maintained, and if so, the charge must be proportional to discharge and slope. It was, therefore, worthwhile finding an empirical relation for silt charge rather by determining it with a number of experiments.

Coming to Chapter VI, giving account of some of the investigations undertaken, the instances given and many others were very well known to him as he had the occasion to discuss all those cases with the author at the C. B. I. Meetings. It was in view of those singular successes obtained at the models by Dr. Uppal, that the felt constrained to say that further elucidation of methods of investigation was very important and desirable.

Khan Bahadur Hamid mentioned of the standardisation of staggered blocks and he (Mr. Chaturvedi) felt that that applied with equal force to standardise methods of experimentation and Malikpur could contribute quite a lot in this respect.

Mr. Montagu said that he had not very much to say on this paper. It was a useful record of work accomplished during the year. But persual of this paper left with him the impression that one had only to apply to the Model Experiment Department of the Research Institute to receive a complete and accurate answer to all our problems. Actually that was not the case. He was the last to decry the help which could be secured from model experiment, but he thought that wise to sound a note of warning that such tests, could not replace engineering design and in particular, engineering experience.

He would illustrate that view by referring particularly to two of the tests recorded in the paper. Shingle exclusion was an essential on the Western Jumna Canal. The situation was extremely serious and unless some adequate remedy was found, that was only a matter of time before the canal ceased to function. The actual remedy proposed by the Research Institute was a shingle excluder in the undersluice pocket at the canal head regulator. He had an aversion for erecting works in the undersluice pockets. No one knew what was coming down the river and such works were difficult to repair and in the event of damage the river could be closed off or diverted for immediate repairs. Moreover that was difficult to foretell what stresses the works would have to withstand with varying discharges in the river.

The undersluice shingle excluder was constructed at Tajewala during last cold weather. It was opened as soon as the river rose and surplus supply was available. For a week or so it was quite satisfactory and so far as we could see was performing its function or excluding shingle from the canal. Unhappily it deposited the shingle below the head regulalator and during that week or so deposited so much that it choked its own effluent. The shingle excluder ceased to function and in due course choked itself solid. What was more, the roof was seriously damaged.

Since then experiments had been conducted by Research Institute as to the best shape of an affluent channel. It will be necessary to construct a very long divide wall and a masonry channel which will conduct the affluent discharge with a very heavy load of shingle at a slope less than the mean slope in the river. It looked as if it would become necessary to lengthen this affiuent channel as shingle was deposited each season until, he supposed, in course of time it might arrive at Delhi.

The experiments on the Beas Training were not altogether as satisfactory in practice as perusal of the paper would lead one to believe. Might he emphasise once more that the beds of silt carrying rivers were constantly rising. In due course if left to themselves, avulsion would take place and the river stream would be returned into relatively low lying ground and the process would be repeated. As soon as man began to cultivate the land and build cities, he endeavoured to protect his work from damage by river floods. River training started but never ended. Surely there had been sufficient experience throughout the world to prove this without any shadow of doubt. A trifling alteration in a silt bank upstream of training works, might alter the direction of onset of the stream and completely destroy those works. Alternatively, the river might leave those works high and dry!. They had experienced both developments in connection with the Beas Training works.

The author had referred to his experiments on a pitched island. The idea lying behind these model tests was not new. As far back as 1926, Mr. Nicholson expressed to him his view that a pitched island above the Suleimanki Headworks might ensure a proper approach to the weir. In 1932 Mr. Nicholson prepared a complete scheme for the Khanki Headworks. The proposals were negatived on the ground of expense. In 1936, the Research Institute carried out a series of most successful model experiments for a similar construction above Islam. These proposals were turned down on the score that it was not possible to get at the work for maintenance purposes during the flood season.

His own experiences both at Tajewala in connection with river training and in the canal in connection with canalisation of the Main Line Upper, convinced him that in certain strictly limited conditions, a pitched island would be of value. The Research Institute started fresh experiments in March 1943. These were most encouraging and a full scale test would now be carried out above the Suleimanki Weir on the Sutlej Valley, they hoped, during the approaching hot weather. The 'island' has just been constructed.

He did not suggest for one moment that pitched islands were the solutions of all river training problems. Their use was restricted to specific conditions. But giving those conditions, it was his conviction that they formed a most valuable item of river control works. He trusted that he would be in a position in conjunction with Dr. Uppal to present a paper on this subject to the next Congress.

R. B. Kanwar Sain said that the necessity of model experiments in Hydraulics was not fully realised by some of the Engineers. He remembered that he put up an estimate for about Rupees 9,000 for carrying out experiments in connection with Trimmu Barrage which experiments were carried out at Malikpur. Mr. Bedford had pulled him up saying that while he was not against spending money on experiments, the experiments should be no excuse for extravagance. That was in August 1937. The expenditure at Malikpur on experiments last year and this year would be of the order of Rupees 80,000 including work charged establishment. This shows how the point of view has steadily changed from 1937 onwards.

Regarding the necessity of carrying out experiments on models, he said that he might quote from the great scientist Galileo Galilei. In 1630 he remarked that 'the laws controlling the motion of the planets in their celestial orbits were better understood than those governing the motion of water on the surface of the earth.' And this was, in a sense, still true in 1944.

There arose in hydrodynamics many problems which defy purely mathematical solutions. It was the purpose of a hydraulic model to provide the means for investigating such problems. The principles of hydraulic similitude insured that the results obtained from investigation of the model would be transferable, quantatively or qualitatively, to the prototype. Perfect similarity of model to prototype was rarely attainable, and, in fact, was not essential so long as the principle of transferability of results was observed.

Practice of fixing various scales varies in various laboratories of the world. In 1939, when he visited Waterways Experiment Station at Vicksburg the vertical scale was usually larger than horizontal scale. This was fixed from dynamic requirements. The discharge and time scales were worked out by trial.

Distortion of the vertical scale produces a model channel whose hydraulic properties are different from those of the natural channel. For this reason, distortion should be held to a minimum, but experience at Malikpur as well as at Vicksburg has indicated no limit beyond which distortion must not be carried. European practice holds to the limit of 5 to 1, as first suggested by Reynolds. In general, however, every laboratory seems to follow a course adopted by the experience gained in the particular laboratory.

As has been indicated by Dr. Uppal, model experiments save large sums of money in certain cases. In all important hydraulic works it would be a good practice to provide a small percentage up to one per cent for model investigations in the estimate.

Dr. Uppal has done full justice to the subject. The paper has many useful aspects. One of them is that and it indicates the data and the information required before undertaking the model experiments. In the past we have found that data supplied were generally inadequate and had to be collected by special requests and reminders.

Mr. Sawhny said that in his opinion the two hydraulic laboratories, were very good exhibitions show but had not got the same experimental value as the Research Station at Malikpur or other field stations which undoubtedly have produced some really useful and reliable results. As a matter of fact even the models constructed at Malikpur are far too clean and regular, for the results of experiments obtained therefrom to be advantageously applied to channels as they actually are to be founded in the province.

It is like testing the efficiency of a car on the Lahore Mall and then cursing our luck for the mileage per gallon done and the jolts received when we are going on the same car along a gadda damaged boundary road or even some canal inspection banks.

Trays as arranged are a very fine table dressing, but he was afraid small tray allotted to silt ejectors would not prove spacious enough to give really sound and accurate results.

It is very nice to have such fine and sensitive instruments like the Pointer Gauge and Pitot Tubes, but troubles start when they compare and apply the results thus obtained to the data actually collected by most irresponsible and careless very low paid staff, who in some cases even are put on these jobs just to serve for a few months during summer when they just aim at making what money they can gather by fair and foul means and leave behind a hopeless mess of gauges etc., etc., for these laboratory results to be derived from or applied to. Hence he said that he would like to give his usual warning but with a bigger force this time that it is high time that the condition of affairs existing in practice on the canals and Headworks where so much of important data are being recorded daily is more promptly looked into and conditions changed very materially otherwise all this scientific advancement will instead of producing the good results that it should, it will be just landing us in an inextricable mess, and instead of our thanking the author for economies that he has shown as having been resulted on account of model experiments they will be blaming him for all their future troubles.

CORRESPONDENCE

Mr. Inglis congratulated Dr. Uppal on his extremely well-written paper which should prove very helpful to new Provincial Research Stations.

Regarding the Beas model : Mr. Inglis recalled that when things went wrong, he was asked by Mr. Dench to advise on the question ; on 18th April he wrote :

"As erosion extends a cut-off must occur if the river is held at Spur C on the right bank, *unless Spur 1 on the left bank pulls the river across to it*, thus stopping further erosion along the right bank downstream of the head of Alma Creek. This is my great objection to Spur 1."

Again on 25th June 1943, he wrote :

"My reason for objecting to the left bank spurs is that though spurs designed for certain conditions may act excellently under those particular conditions, yet the effect of a groyne with an armoured spur nose is to concentrate flow from a considerable width of river towards the nose of the spur. This causes a deep scour hole to develop, which in turn, draws still more flow towards the spur and hence still deeper scour occurs. When the flood decreases, flow towards the the spur persists and the axis of the river is pulled towards the spur and held there.

From this it follows that it is undesirable to construct groynes at a point where there is danger of an avulsion taking place."

" Actually the embayment had almost attained its natural maximum in 1940; and had a retired bund been constructed, the river would have cut across from a point near A to B; but the construction of groynes 2 and 3 prevented this."

" When I inspected the river I was told that it was out of the question to remove Spur 1 before this (1943) flood season; but there is quite a possibility that it may capture the river before Spur C can pull it away and it will always tend to pull the river just where this is not wanted."

This is exactly what happened.

The question of importance is not whether the model gave a correct forecast of what would happen for one year ahead under certain assumed conditions; but whether the groynes constructed were the best long-term solution. Obviously they were not.

"On page 24 Dr. Uppal states 'the dominant river discharge at the (Beas) spurs in 1942 was twice as much as discharge in normal year." This statement is entirely incorrect; and it appears that Dr. Uppal must mean average discharge or something quite different from dominant discharge. Dominant discharge is defined as "the discharge which determines meander length."

Actually the dominant discharge approximates to bank full discharge and when the river flow is over the berms the dominant discharge ceases to have any meaning and, in general, dominant discharge does not vary widely from year to year."

Mr. Inglis said he was also called in to advise on the question of the design of a pebble excluder at the head of the Western Jumna Canal at Tajewala. When he visited the station on 20th July, 1942, he stressed the beneficial curvature of flow at this Headworks and suggested determining the lines of flow.

Subsequently, he wrote :

" I consider that Tajewala tunnel excluder design is likely to be highly satisfactory as it makes use of curvature of flow and hence economises the water required. But I hold that unless a lined channel is built along the right bank of the river below the excluder to carry the debris from the excluder well down the river, the excluder tunnels will block up."

This is exactly what happened in the prototype during the 1943 floods.

Regarding experiments on the length of divide walls at the Kalabagh Headworks, it is stated :

" As the length of the divide wall decreases, the silt entry into the canal diminishes. The investigation showed that a divide wall 300 ft.

in length constucted at the fourth pier is preferable to either 450 ft. or 600 ft. in length."

These results confirm those reported in Bombay Technical Paper (1) No. 52 published in 1934.

Regarding experiments on the width of the pocket, it is stated :

(*ii*) The silt entering the canal when the divide wall is constructed at the 7th pier is much less than when the divide wall is constructed at the 4th pier.

(*iii*) The velocities in the pocket with the divide wall at the 4th pier are much higher than those obtained when the divide wall is at the 7th pier."

These results confirm those obtained in 1920 at Poona reported in Bombay Technical Paper No. 45 (2) in which it is stated :

" A long series of model experiments with discharges varying from 3 to 30 cusecs has been carried out at Poona from which it has been found that if a divide wall is constructed in a straight stream—thus creating an approach channel in which the velocity as compared to that in the main stream can be regulated—the silt draw depends on the ratio of V/Vs** ratios inside and outside the divide wall ; so that when the V/Vs ratios are the same, the stream and silt charge are equally divided. Consequently if the velocity in the approach channel is reduced, so as to give a lower V/Vs ratio in the approach channel than in the river, the proportion of bed silt entering the approach channel is less than that passing down the river ; and if the velocity ratio is considerably lower in the approach channel than in the river, practically the whole of the bed silt can be excluded.

As regards Mr. Montagu's statement to the effect that the idea of using islands to centre flow is not new and that he had discussed the the question with Mr. Nicholson in 1927 : Mr. Inglis thought that this did not give a true picture of the case ; because after he had suggested an island above Suleimanki to Mr. Mckenna ,in 1929-30 to ' centre ' the flow, he had discussed this with Mr. Nicholson, whose idea was an ' island divider ' much nearer the Barrage. This was a distinctly different concept from that of an attracting island, and would not be a success.

With reference to the Author's statement on page 39 :

" The river gauges on the model can be predicted with great accuracy and also the current direction and velocities. It is possible to

(1) Bomday P.W.D. Technical Paper No. 52 " Factors affecting Exclusion of bed silt from canal taking off from alluvial rivers " by C. C. Inglis and D.V. Joglekar.

(2) Bombay P. W. D. Technical Paper No. 45 " Silt exclusion from canals still Bend *versus* Semi, open flow" by C. C. Inglis.

(***Note*.—V_S is the stable mean velocity on a vertical for a particular depth and silt at a particular point in a stream) ; and is effected by the ratio of bed width to depth, *i.e.*, shape of channel). The exponent varies from about 0·5 in large channels to 0·64 in small channels ; but a small error in choice of exponent makes little difference in the result.) "

predict bank erosion with reasonable accuracy and also the depth of scour. Thus it is possible to forecast the river behaviour on the model."

Mr. Inglis wished to call attention to the fact that the Malikpur experiments quoted have been carried out for existing conditions, and that the discharge and even the bed material were changed until the model results agreed with the river data. It is not surprising, therefore, that "river gauges on the model can be predicted with great accuracy and also the current directions and velocities;" *but this is only true for so long as no considerable changes take place in a river.* It is also possible, by using a suitable material in the banks, to simulate the erosion which takes place under particular assumed conditions *for a short period of time;* but it does not follow from this that "it is possible to forecast the river behaviour on the model" *except for a short period of time.*

Experience shows that where silting and erosion are considerable, mobile models cannot predict for more than a few years ahead; firstly because there are too many unknowns regarding materials in the bed and banks where erosion and scour will occur; secondly because the sides cannot stand to the vertically exaggerated scale; thirdly because rigid features have a highly exaggerated effect; fourthly because silt and sand movements in a model differ from those in a river; fifthly because changes in a model depend on entry conditions, *i. e.*, on river conditions upstream, which must be predicted from experience; and sixthly because the time scales for silting (*i.e.*, deposition of fine silt) and sour differ widely in the model instead of being the same, as they would have to reproduce long-term similarity.

These statements are made because the vast majority of practical Engineers, so far from being reassured by claims of extraordinary accuracy are only rendered still more suspicious thereby. The object of model experimentation is not to reproduce what has occurred after the event nor for a year or two ahead; but to enable the experienced Engineer to ascertain details connected with what he knows is likely to occur in years to come, and especially to check up on the worst conditions which he foresees may occur, not next year nor the year after, but 10, 20 or 30 years ahead.

I give this as a warning to those who still believe that river control can be brought down to mere model experimentation. It cannot. Mobil river models are a valuable aid to engineering experience and skill, which, however, they can never replace.

Dr. Robert *V.* **Burns** communicated that he had read Dr. Uppal's Paper on the Hydraulic Research Station Malikpur with a considerable amount of interest, and wished to congratulate him on the amount of detail which he had given. His visit to Malikpur last year was very helpful in reading this paper.

2. In comparing this station with other hydraulic laboratories visited, there seemed to be one outstanding difference and that was the sizes of model used for experimental purposes. The Punjab river models

at Malikpur are generally much larger than those which he had seen elsewhere.

3. He wrote that he would like to ask the author if he could supply the answers to a few questions which came to his mind while reading his paper as follows :

Page No. 1. Reference is made to small-scale and large-scale models.

Where is the dividing line between small-scale and large-scale models, or shall we say small, medium or large-scale models ?

Why does the Punjab Irrigation use such large-scale river models ?

What are the advantages and disadvantages of large and small-scale river models ?

How does the cost of river models vary with the scale ?

How much did the various models mentioned cost ?

Page No. 1. How much time was required for the various investigations described ?

How many men were employed in setting up the various models ?

Are the workmen given special training before being allowed to work on model construction.

Page No. 3. —What sort of construction is 'pacca' in speaking of outfalls into the supply channel ?

Page No. 5. What are the references for the Binkley and Bose Samplers and the Uppal Siltometer ?

Page No. 7. What is a bela ?

Page No. 10. How is the amount of distortion, which should be given to a model, determined ?

What is meant by "the Reynold's numbers are very large" ? How large ?

How does the author adjust the model scales, where bank erosion is being studied, considering the angle of repose of bed materials ?

What are the references for the equation stated, *i.e.*, for Manning's, Kutter's Winkel's and Lacey's formulae ?

What are the references when speaking of Krey and others ?

Page No. 11. What are the references when speaking of Froude's, Manning's and Vogel's work.

Page No. 15. Have two or more models of different scales ever been set up to study one particular problem ? If so, in what respect did the results *differ from one another ?* The actual difference is wanted and not the argument.

Pages 34 and 36. How are the efficiencies of various designs calculated ? What are the factors which effect the scale sizes of models ?

4. It is assumed that a distance of 1" (page 9) is "too small to allow any accurate observations to be made." In view of the fact that

he had made accurate observations in cuts (on models) much smaller than 1" he could not agree with the statement. It is also stated in this same paragraph " as the horizontal scale governs the discharge scale, etc." He did not agree, since the discharge scale was a function of both the horizontal and vertical scales.

5. In Ceylon the procedure adopted for the construction of models (page 13) is to use the co-ordinate system for the surveys and setting up of the models. This method has been found more satisfactory than the use of a reference line as described in the author's paper.

He wrote that he would like to thank all the Officers of the Irrigation Research Institute, Lahore for the pains they took in showing him around last year and especially to Dr. Uppal who took him to see the Hydraulic Research Station, Malikpur.

The *Author* thanked the various speakers who took part in the discussion.

In reply to Mr. A. R. Khanna, Dr. Uppal said that from the model experiments a forecast regarding the probable river conditions to be experienced at the end of 1940 was made. The model results obtained for 1940 monsoon should be compared only with the results obtained on the prototype after monsoon 1940. There is little justification in comparing the forecast from the model results for 1940 monsoon with the conditions experienced on the prototype in 1942 or 1943.

The results obtained on the prototype at the end of 1940 agreed very closely with the observations of the model experiments contained in the forecast report for that period, as stated in the paper on page 24. Even the conditions on the prototype obtained in 1941 agreed considerably with the 1940 model observations.

In 1942, as already mentioned on page 24, unprecedented high floods of very long duration were experienced in the River Beas. The river approach considerably changed upstream of Spur 1. The right arm of the river developed in 1942 and directly hit the left bank between Spurs 1 and 2. The question of position or number of spurs in this case does not arise when the river attacked the left bank in the position shown in the margin.

The speaker admitted the utility of the model experiments The author has not stated anywhere that the model experiments will give quantitative result for all cases and in this case, however, the question does not arise, since the model had not been tested for the conditions experienced on the prototype in 1942 or 1943.

Dr. Uppal thanked Mr. Hamid for his valuable contribution to the paper and said that for the Western Jumna silt excluder constructed at Tajewala Headworks, the two main features were (1) the small area of opening of the tunnels and (2) the curvature flow. For the conditions of flow existing in front of the head regulator at Tajewala, the design shown in Fig. 18-A was most satisfactory. Jaba type silt excluder mentioned by the speaker could not work satisfactorily under these conditions. However, since the model of Tajewala existed, proposals put forward by Mr. Hamid will be tested.

In reply to Mr. Vadera, Dr. Uppal stated that it was gratifying to learn from an officer who was in charge of the works, that the prototype observations agreed closely with the model results, and that the excluder tunnels worked efficiently. The choking up is due to the absence of a proper outfall channel as already stated in several reports on the work.

The design of the outfall channel was being examined on the model. The most suitable dimensions for a lined outfall channel capable of disposing off the whole of the detritus brought down by the River Jumna were being determined. It was expected that the results would be available at an early date.

In reply to Mr. R. S. Chatturvedi, the author said that it was not possible to go into more details in this paper. For further information, references were given in the paper.

An attempt is being made to standardize method of experimentation.

The author thanked Mr. Montagu for his great interest in the research work and his valuable contributions. As stated in the paper, the outfall channel was considered to be very essential for the excluder, as otherwise it would become choked up.

As mentioned by the speaker, considerable amount of work has been carried out on the effect of construction of pitched island on river training. Besides testing these on Suleimanki Headworks, islands have been examined at other places, such as River Indus above Glancy Barrage, River Ravi at Bherian Spurs, and River Sutlej above Islam Headworks ; and satisfactory results have been obtained.

The author thanked R. B. L. Kawar Sain for his great interest and helpful comments. His sympathetic attitude before taking charge of the Irrigation Research Institute and later as Director was of great help in developing the Station.

In reply to Mr. Sawhney, the author said that it was for the speaker to see that the correct data was sent to the Irrigation Research Institute. It is perfectly true that for obtaining correct results from the model, data supplied by the local officers should be very accurate and some organization is required to control it.

With regard to the comments sent by Mr. Inglis, it may be mentioned that in a meeting held on the 2nd of March, 1943 in which Mr. Inglis ; Mr. Dench ; Mr. Haigh ; Superintending Engineer, Drainage Circle ; Director, Irrigation Research Institute and the author were present, the proposals put forward by the speaker were considered. Mr. Inglis's proposals at that time consisted of :

1. A collapsible spur downstream of Spur No. 3.

2. Constructing a Retired Embankment behind the existing embankment between Spurs 1 and 3.

3. Laying stone apron at certain portions of the embankment.

At the time, Mr. Inglis did not propose the removal of Spur No. 1. If Spur C, proposed by Mr. Inglis, was to work only in the absence of Spur 1, then the first proposal should have been to remove Spur 1 and then construct his Spur C.

Experiments on the most suitable design of a lined channel for the Tajewala Excluder are in progress.

In reply to last para of Mr. Inglis's comments, it may be stated that it has always been opined that model experiments are a valuable aid to the designing Engineer and that is all. There are types of models which give quantitative results and there are others which can give only qualitative results, and there are still others which may not be of much help.

In reply to Dr. Burns' questionnaire, the following replies are given :

There is no hard and fast dividing line between small-scale and large scale models. We could say small, medium or large-scale models. This is all relative.

Large-scale river models are used as it saves the trouble of making part models. Secondly, the problems on the Punjab rivers mostly relate to river diversion, river training, etc. Now river diversion, etc., is made only when the river discharge is very low. If the models were very small, no definite results could be obtained. After a good deal of experimentation, it was decided to use the scales advocated in the paper.

Regarding the advantages and disadvantages of large and small scale river models, the writer is requested to refer te Hydraulic Laboratory Practice, by John Freeman (1929 *Ed.*)

The cost of the river models does not vary proportionately according to the scale. Since the Headworks models are maintained and kept for any further tests, the original cost of construction does not matter very much.

Generally a river model costs about 3,000 to 4,000 rupees in these days of war conditions. The time required for the various investigations is from six months to one year.

The workmen are given special training before they are allowed to construct models.

The word 'Pacca' means rigid structure—may be in cement concrete or brick or stone masonry.

For Binkley and Bose Samplers, and for Uppal Siltometer, reference may be made to Annual Reports of the Irrigation Research Institute.

A Bela is a dry piece of land in the river.

The distortion which is given to each model is determined experimentally.

The Reynold's Numbers at Malikpur, in most cases, are more than 80,000—1,00,000.

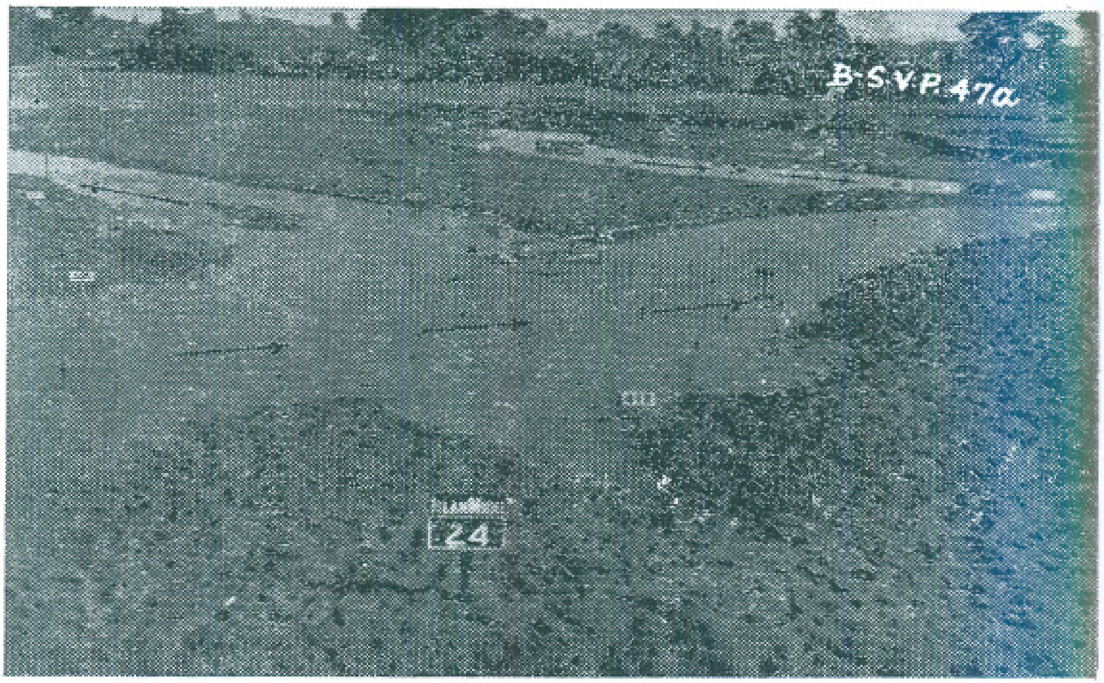
Models of different scales for the examination of particular problem have been tested in several cases. The difference, in most cases, has not been much.

It is surprising to learn that the writer carried out accurate work with cuts much smaller than 1″. 'Much smaller than 1″' means about ½″ and less. The accurate work for river diversion, etc., on cuts ¼″ or ⅓″ wide is something which cannot be imagined.

It should be that 'as the horizontal scale also governs the discharge scale.'

SHOWING A CUT OFF OCCURRING AT MILE 7

Fig.



From an examination of this photograph, it will be seen that a large loope has become silted up and the river flow has straightened.