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RIVER TRAINING AND CONTROL BY PITCHED ISLANDS

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N. B. —The figures marked with asterisk could not be printed due to lack of funds. These are available with the Hony. Secretary, Punjab Engineering Congress, in the original copy, for reference.

RIVER TRAINING AND CONTROL BY PITCHED ISLANDS

SYNOPSIS

A brief survey of the current methods of river training and control has been made.

A new method of river training by means of stone pitched islands has been developed. The method has been fully examined in the glass flumes in the Hydraulic Laboratories, on large-scale river models and on the full scale on the actual river.

Results obtained on models of rivers :—

1. Sutlej above Islam and Suleimanki Headworks,
2. Indus at Kalabagh,
3. Ravi downstream of Madhopur Headworks, and
4. Beas near Western Bein, have been discussed.

Observations made on the River Sutlej above Suleimanki Headworks in the presence of a pitched island have also been discussed.

It has been shown that the stone pitched islands constructed at suitable places on the river bed help to straighten the river course above the barrages. Where the barrages are large, more than one island may have to be used.

The use of the pitched island helps in :—

1. Training the river central above the weir.
2. Relieving the intensity of flow on the marginal bunds, the guide banks and outside of river curves.
3. Training the river in the reach away from control points.
4. Protecting the valley land against devastation as well as reclaiming it.
5. Improving channels for navigation.

RIVER TRAINING AND CONTROL BY PITCHED ISLANDS

INTRODUCTION

1. Physics of River Flow. Rivers flowing unrestrictedly, through incoherent material meander or adopt sinuous courses. Various hypotheses have been put forward from time to time to explain this phenomenon. Dubuat in 1786 held the view that the original course of the river was straight and the meandering occurred due to the deflection of the river from a straight course by an obstacle.

Stanley and Exner ascribed this to the formation of alternate eddies as those developed behind a cliff. According to James Thompson, the development of curves was due to secondary flow.

The Geologist and the Morphologist attribute this phenomenon to the rotation of earth, which is khown as Carioli's affect or Baer's Law. Qureshi's experiments carried out in 1943 confirm Thompson's explanation.

The effect of the charge of material carried by the rivers, the discharge, and the bed slope on the meandering, have been the subject of a detailed investigation at Malikpur and at Vicksburg.

Whatever may be the explanation of the origin of meandering, the fact remains that meandering is the universal characteristic of natural streams, and occupies the most important place in river training.

In the Punjab, a premier irrigation province depending for its irrigation on canals, the river Indus and all its tributaries are tapped. There are fifteen major canal headworks. With such an extensive canal system, the proper training and control of the rivers at each headworks is of paramount importance to economical operation.

2. Punjab Practice in Construction of Headworks. Punjab Engineers have constructed no less than fifteen headworks on rivers in or adjoining the Punjab. As a result of this experience, it is their practice to construct new headworks away from the main channel of the river, and if possible, in the neighbourhood of a loop. When construction is completed, the river is diverted over the new weir and the main channel closed by means of substantial bunds. One effect of this method of construction is to impose on the river at least two extremely sharp curves. The river seldom straightens itself and if these bends persist, may give rise to considerable difficulties in maintaining the retired embankments and guide bunds as well as marked variations in the distribution of silt in the water entering the pond.

Guide banks as the original training works and their inefficiency. Originally a system of guide banks was the only training works constructed at the headworks. This alone, however, has proved to be insufficient. The discharge in the river varied very considerably, from many thousand cusecs in summer to a few hundred in winter. Consequently, belas or

sandy islands form at undesirable places in the pockets between the guide banks etc. Rivers must be trained for a considerable length upstream of the weirs. If not properly trained, the river may cause :—

1. Heavy action at one or the other marginal bund. It may even threaten to outflank the weir by cutting through the marginal bunds.

2. Heavy action at the noses of the guide banks, resulting in high annual expenditure.

3. Oblique approach to the canal regulators, resulting in unfavourable silt conditions in the pockets.

4. Overstraining of certain portions of the weir bays.

5. Location of the deep channel downstream of the weir at undesirable places.

It is, therefore, essential that satisfactory methods of river training should be adopted.

3. **Current Methods of River Training.** Current methods of river training are described very briefly below :—

(a) The American Practice. In America, considerable amount of work has been carried out on training the Mississippi River at different reaches, both in the lower and the upper Mississippi. One of the difficulties in the Mississippi river is, that during the low water where excessive river width and steep slope occur, very troublesome sandy shoals form at several crossings. The depth becomes small and insufficient for navigation. The crossings are, therefore, a source of trouble to navigation and the following methods have been studied to train the channel along the desired course.

Permeable Spur Dikes. The method adopted is mostly the construction of permeable spur dikes. Navigation problems at four points; *i.e.*, Fort Charters, Hotch-Kiss Bend, Brooks point and Point Pleasant where the crossings had shoaled, were studied by means of models, by Fogel. The dike system both for the left and the right banks, in order to control the meandering of the river during low water, was adopted. This is illustrated in Fig. 1* and 1-A*.

Training Walls. Training walls force the river into the desired position and are expected to hold it there. They are constructed in the original river bed. The upstream end of the wall is keyed well into the old bank and often transverse dikes are also built between the old bank and the training wall. The silt laden water is permitted to enter the area between the old bank and the training wall. By reducing the velocity of flow, the silt can be deposited and the low area thus reclaimed.

Groynes. Groynes are transverse dikes built up from the abandoned bank to the proposed bank line to contract the channel and to cause accretion in the part of the channel behind the proposed bank line. The pool forms at the head of the groyne. Groynes may be of different types :—

N. B.—The figures marked asterisk could not be printed due to lack of funds. These are available with the Hony. Secretary, Punjab Engineering Congress, in the original copy, for reference.

1. Non-overflow groynes in which the crest is placed at flood stage.

2. The overflow groynes in which the crest is placed at the main water level stage.

Groynes do not works satisfactorily in mountain streams.

(b) **The Indian Practice.** In India, and specially in Punjab, besides guide banks, several other training works have been constructed in the rivers above barrages. The training works chiefly consist of armoured spurs constructed at suitable points on the river banks. The types of armoured spurs adopted in the past are:—

1. Hockey Spurs.
2. Inverted Hockey Spurs.
3. Point Spurs.
4. 'T' Head Spurs.

The type found to be most satisfactory is the 'T' Head Spur. The spurs are constructed in stone with heavy aprons. Various arrangements of these spurs have been adopted in the past.

Spurs constructed along one bank of the river. In some cases, spurs have only been constructed along one bank. An example of this is the river Chenab above Khanki Headworks. At this place more than a dozen spurs exist along the right bank.

Spurs constructed on both banks of the River. In other cases, spurs on both banks of the river have been constructed. On the River Ravi above Balloki, armoured spurs exist on both the banks, thus tightening the river.

On the old weirs of the Punjab, large natural belas exist in front of the central bays of the weir. These belas extend sometimes for a length of two to three miles, as at Khanki, Rasul, etc. In these cases, the central bays of the weir are masked and their capacity to escape the flood discharge is reduced. From a perusal of the above, it will be seen that methods adopted in the past for training the river were not very satisfactory.

4. The Pitched Island Idea. The idea of pitched island first originated with H. W. Nicholson, in 1926-27. Later on, when in charge of Khanki Headworks, he submitted proposals to Government in a note dated the 24th April, 1933, for pitching the nose of the central bela but the proposal was rejected.

The effect of the pitched island on river training was examined by means of models by Uppal and Mushtaq Ahmad in 1936. In addition, other methods of river training, *i.e.*, armoured spurs constructed at different places, on both the river banks and on one bank, extension of the guide banks and the sandy belas along the guide banks were examined. Results obtained showed that the conditions obtained with the pitched island were the most satisfactory.

Revival of the pitched island idea. In 1943, Montagu again revived the idea of the pitched island.

Theory of the pitched island. The construction of a pitched island in the river bed effects a change in the velocity fluctuation and the tractive force. The tractive force near the island considerably increases and causes scour. It draws slowly the main river channel on to itself and holds the river there. The working of the island is satisfactory, especially in the vicinity of control points, *i.e.*, weirs and railway bridges.

The object of this Paper is to give an account of the results of recent investigations.

A STUDY OF THE PITCHED ISLANDS BY MEANS OF MODELS

1. 1936-37 STUDIES.

Unsatisfactory river approach at Sutlej Valley Project Barrages. The approach of the River Sutlej at all the S. V. P. weirs since their construction has been oblique with large bela formation between the guide banks, resulting in unfavourable silt conditions in the pockets. In certain cases, the feeding of the canals became difficult.

In the year 1935, the question of improving the design of river training works on the S. V. P. was under consideration. Proposals for effecting improvements in the training works were put up to the Government. Before the schemes could be adopted, it was decided to investigate the most satisfactory design of the works by means of river models. It was proposed to examine models of each of the Sutlej Valley Project Barrages. The River Sutlej at Islam Headworks was taken up first because the trouble was acute.

The problem at Islam Headworks. The weir at Islam was constructed some distance away from the main river and on completion the river was diverted to the weir. The training works constructed were unable to make the river approach straight. A tortuous channel developed upstream of the weir. In 1936, the main stream had developed along the left bank to such an extent that the right pocket was fed with the greatest difficulty.

It was, therefore, required to study methods to control the river so that the bela near the right guide bank should not extend and the main river flow between the guide banks should be straight.

The models. For the purposes of this study, a length of about three to four miles of the River Sutlej above the Islam Weir was selected for modelling. Two models of the movable bed type were constructed to the following scales :—

Model No. 1	Horizontal Scale	Model to prototype	1-1000
	Vertical Scale	Model to prototype	1-100
	Exaggeration		10

Model No. 2	Horizontal Scale	Model to prototype	1-750
	Vertical Scale	Model to prototype	1-80
	Exaggeration		9·4

The size of the sand particles which enabled the model to reproduce the conditions of the prototype was approximately of 0·15 mm. diameter.

After proving the models, devices to secure the removal of the bela along the right guide bank were examined.

Construction of an artificial bela or a pitched island on the river bed upstream of the Islam Weir. A pitched island or an artificial bela, as it was called at that time, was constructed in the river bed about 5,000 ft. upstream of the Islam Weir. The position selected was between the centre-line to the weir and the left edge of the large bela between 'T' Head Spur and the nose of the upstream right guide bank as illustrated in Fig. 2. The bela was triangular in shape with one side parallel to the right guide bank and the angle between the two sides facing the current was 25°. The effect of the presence of the bela was to divide the current below the 'T' Spur so that a portion of the supply was directed towards the right guide bank. This had the effect of destroying the back-water near the right pocket which was the cause of the formation of the bela.

Fig. 2 illustrates the effect of the bela on the river sections and velocity distribution. The river sections and velocity distribution before the construction of the island and two seasons after the island had been in operation, are plotted. From an examination of this figure, it will be seen that the presence of the bela had the following effects :—

1. Scouring of the bela between the 'T' head spur and the nose of the upstream right guide bank occurred. Bela along the right guide bank was also scoured. A channel formed on the right side of the pitched island.

2. Silting occurred in the left channel which was originally very deep. The velocity distribution between the guide banks improved considerably. Along the right guide bank, where the velocity of flow originally was very low, it rose as high as that in the left channel. The velocity of flow on the two sides of the island at the tail end of the bela was, more or less, the same. Fig. 3 shows the current direction on the model in the presence of the pitched island. The flow is uniformly distributed. Fig. 3-A shows that the river bed between the guide banks is uniform after the run.

Conclusion. The construction of the pitched island produced very satisfactory results. The river flow between the guide banks was considerably improved and became, more or less, central.

An investigation of the most suitable shape and the length of the artificial bela or the pitched island.—Next, different shapes of the artificial bela were examined. Experiments were also carried out with different lengths of the artificial bela. Several runs were made in the presence of the bela

after making the natural bela in the pocket at the right guide bank semi-erodible for the purposes of getting results in a reasonable time. In each case the bela at the right guide bank was scoured out. It was found that the one which gave the most satisfactory results had the following shape and dimensions :—

1. The total length of the artificial bela was 500 ft. starting at R. D. 5,050 and finishing at R. D. 5,550.

2. The maximum width at the top was 30 ft. with a slope of 1 : 1 on the sides.

3. A stone apron for a distance of 50 ft. was laid on both sides of the bela.

4. The R. L. of the top of the bela was 454·0. The up and down-stream ends were streamlined so as to cause minimum scour at these points.

The results obtained with the most suitable shape are illustrated in Fig. 4*, 4-A* and 4-B*. For comparison the original conditions before the construction of the island are also given.

Fixing the width of the section between the 'T' Spur and the left bank. Having decided the best position and shape of the artificial bela, it was necessary to fix the width of the section between the 'T' Spur and the left bank. If this section was not fixed, erosion of the left bank may take place and the artificial bela may be useless. A fresh series of experiments was carried out, the left bank was moulded with a mixture of sand and clay in the ratio of 50 to 50 and the extent to which the left bank was eroded was determined. It was shown from these experiments that it was necessary to protect the left bank between R. D. 4,500 and 6,600 upstream of the weir for maintaining the efficient working of the pitched island.

An examination of other devices. Further experiments were carried out to determine the effect of other devices on the river conditions at Islam. Amongst the devices examined were :—

1. Reduction in the length of the right guide bank.
2. Effect of a curved spur on the left bank.
3. Effect of a pair of armoured spurs, projecting from each bank.
4. Effect of a pair of artificial sandy belas along each guide bank.
5. Effect of constructing leading cuts.
6. Effect of a 'T' head spur upstream of Murphy Spur.

Reducing the length of the right guide bank by 400, 800 or 1200 ft. did not effect any marked improvement in the conditions of flow. The construction of a curved spur on the left bank did deflect the jet towards the right guide bank, but induced silting up along the left guide bank downstream of the spur. Results were unsatisfactory. Construction of a pair of armoured spurs helped to tighten the river and concentrated

the jet in the centre, as shown in Fig· 5* but heavy action occurred at their noses. The sandy belas constructed along the guide banks served no useful purpose.

The construction of the artificial bela or pitched island gave very satisfactory results. The main current upstream of the weir became central.

The pitched island was not approved by the local officers and the idea was dropped, on the plea that it was impossible to have easy access to the island in floods. Therefore, further experiments on the pitched islands were stopped and for six years no work was done on these lines.

2. 1943-44 STUDIES

Revival of the pitched islands idea by Mr. Montagu. In March 1943, soon after his arrival in the Secretariat, Mr. Montagu again revived the pitched island method. A new interpretation was given by him to the working of the island and it was not considered necessary to have accessibility to the island in floods. A fresh study was made :-

1. In the glass flume in the Hydraulic Laboratories.
2. On the large scales river models.
3. On full scale on the prototype.

(a) Experiments in the Glass Flume in the Hydraulic Laboratories. Experiments were carried out in the glass flume to study the behaviour of the stream in the presence of a pitched island. The effect of the shape of the island on the bed of the stream was also studied. Th following observations were made in each case :—

1. Water surface profile along the pitched island.
2. Velocity distribution.
3. Bed Scour.
4. Tractive force.

Tests were made with different conditions of flow in the flume.

Two different designs of pitched island shown in Fig. 6* were examined in the central portion of the glass flume. Sand of the grade 0·2 mm. diam. was placed in the flume for a depth of 8". Experiments were made with :—

1. Constant depth and constant discharge.
2. Constant depth and varying discharge.
3. Varying depth and varying discharge.

Views of the pitched island constructed in the flume are shown in Fig. 7 and 7-A*. The experiments were first made with velocity of flow just below the critical. These experiments showed that with this velocity, while no movement took place at any other point on the bed, scour occurred near the island.

The second indication obtained was that the scour near the island started just upstream of the island and then moved towards the tail end. Just below the tail end of the island a certain amount of deposit occurred.

The maximum scour was obtained with the highest discharge run and when the discharge was decreased, the scour started filling up. The velocity distribution obtained with the two designs of the island is illustrated in Fig. 8* and the bed scour in Fig. 9*.

The Tractive Force Measurements. The tractive force is the force exerted at any point by flowing water on material on the bed and is expressed as :—

$$T = W\ S\ D, \text{ where}$$

T = tractive force in pounds per sq. foot.
W = Weight of water per cubic foot,
S = Slope of the water surface,
D = Depth in feet of the water at the given point.

The tractive force was determined in the centre of the flume near the island and along the sides of the flume away from the island. The results obtained are given in Fig. 10. From an examination of this figure it will be seen that near the island, a considerable increase in the tractive force occurs. This is due to the high slope imposed on the water surface near the island. Due to the increased tractive force at the island, scour occurs at this place ; while at other places, no bed movement takes place. With high discharges when the velocity of flow is great, a deep scour occurs at the nose of the island and extends to the tail end. The scour obtained is circular in shape, in both the rectangular and streamlined models, as shown in Figs. 7 and 7-A.*

(b) Experiments on large scale river models. To study the effect of pitched island in detail, several models were examined :—

(i) A study of the effect of construction of pitched islands on the River Sutlej above Suleimanki Headworks. The River Sutlej above Suleimanki Headworks flows in a tortuous course causing heavy action at one or the other nose of the upstream guide bank. In order to straighten the oblique approach, a model of the Suleimanki Headworks and the River Sutlej for a length of 15 miles above the Headworks was constructed to the following scales :—

Horizontal	Model to prototype	1-150
Vertical	Model to prototype	1-25
Exaggeration		6

After proving the model the following studies were made :—

Study No. 1. Determining the effect of constructing a single pitched island in the river bed.

2. Determining the effect of constructing a series of pitched islands in the river bed.

3. Determining the effect of constructing a series of pitched islands joined to each other and the main river by a leading cut.
4. Determining the effect of constructing a series of pitched islands joined to each other and the main river, main river also closed by an earthen bund.
5. Determining the effect of constructing a single pitched islands close to the noses of the guide banks.
6. A comparison of the river conditions in the absence and in the presence of the pitched island constructed at 4600 ft. above the weir.
7. An examination of the design of the pitched island on a large scale model.

A brief account of the results obtained in each study is given below. Photographs illustrating the conditions of flow during the operation of the model and after run are also attached. Observations regarding velocity, depth of scour at various points near the island, gauges, channels, and bela formation were made in each case. After each complete run a detailed survey of the river bed was made. In case of each study, except No. 7 the model was moulded to November, 1942, river survey, and the following river-discharges were run :—

Stage 1. Mediun river condition.
Discharge 80,000 cusecs.

Stage 2. Flood conditions.
Discharge 1,00,000 cusecs.
1,50,000 ,,
2,00,000 ,,
2,50,000 ,,
3,00,000 ,,

Stage 3. Medium discharge 80,000 cusecs.
Run for a period equivalent to one month (long period).

Study No. 1.

Determining the effect of constructing a single pitched island in the river bed.

At 7170 ft. above weir, a bela existed and the main river was situated towards the left side of the centre-line at a distance of 700 ft. It was decided to examine the following two positions of the island :—

1. Pitched island constructed midway between the right edge of the main river and the centre-line.

2. Pitched island constructed on the centre-line.

1. Pitched island constructed midway between the right edge of the main river and the centre-line. Fig. 11* shows the island constructed midway between the right river edge and the centre-line to the

weir. The model in the presence of the island was run for the river stages mentioned above and all the necessary observations were taken. A survey of the bed after run is illustrated in Fig. 12*. The following indications were obtained :—

(*i*) The presence of the island pulled the river on to itself. The deep channel, which was situated well away from the island on the left side before run, now existed close to it.

(*ii*) A deep scour hole occurred at the nose of the island.

(*iii*) The main channel above the island became deflected towards the right side due to the presence of the island.

2. Pitched island constructed on the centre-line. The island was removed from the first position and reconstructed on the centre-line to the weir. The river bed at the old position of the island was not remoulded.

The model was tested as before for all the stages of flow and the necessary observations were made.

The directions of flow with a discharge of 2,50,000 cusecs showed that the main flow occurred at the nose of the island. Downstream of the island, the river divided into two parts. The conditions of flow at the end of the run are illustrated in Fig. 13-B. This figure shows that the flow between the island and the weir became central. For comparison, photographs showing the original conditions and the conditions obtained after running the model in the presence of the island in the first position are also given in Figs. 13, 13-A and 13-B.

Conclusions. The following conclusions were drawn from this study :—

1. The river approach to the weir could be made straight by constructing a pitched island in the river.

2. The construction of a pitched island attracts the main channel towards it and a bela forms at the position of the original deep channel ; as shown in Fig. 13-B.

3. When the main channel exists at a large distance from the centre-line of the weir, shifting of the channel to the centre-line would have to be effected in stages.

4. The main channel above the island has also been influenced. The distance up to which the influence of the island extends in this case is about 800 ft.

Study No. 2.

Determining the effect of constructing a series of pitched islands in the river bed.

In this study the effect of the construction of a series of pitched islands was examined. The first island constructed in Study No. 1 was allowed to remain there.

Effect of two pitched islands. A second pitched island was constructed 6,000 ft. upstreams of the first. There is a high sandy bela at this place.

For the second pitched island two positions were examined :—

1. Pitched island constructed at 450 ft. from the right edge of the main channel or 1800 ft. from the centre-line.

2. Pitched island constructed on the centre-line.

The model was run with different stages as in study No. 1. A slight alteration was made in this case. Instead of running 80,000 cusecs for a period equivalent to one month, a discharge of 1,00,000 cusecs was used, since the bela on which the second island was constructed was high and with 80,000 cusecs discharge little flow took place over the bela. Fig. 14 illustrates the conditions of flow with a discharge of 1,00,000 cusecs. The indication obtained from the running of the model was that the main current upstreams of the island appeared to shift towards the centre-line. The river made a large loop on the left side opposite the island.

It may be pointed out that the success of Island No. 2 depends upon the duration of the discharges which flow over the bela and the magnitude of floods. Since water over the bela on which Island No. 2 is constructed flows in high discharges, it is the duration of these discharges which matters. The conditions at Island No. 1 were very satisfactory.

The island constructed in the last experiment at 450 ft. from the right edge of the main stream was removed from there and placed on the centre-line. The bed conditions were not altered. The model was run with different discharges and the necessary observations were taken at each stage of run.

The depth of water over the bela on which the second pitched island was constructed was still very small. The main flow in the river opposite the second pitched island occurred at a large distance from the island. The whole of the river was, however, concentrated at the first island. A survey of the river bed was made after the completion of the run and is shown in Fig. 15*.

Conclusions. One of the conclusions obtained from this investigation is that the main stream divided into three parts, the left channel is not very deep and the bela on which second island was constructed has been lowered by scouring action. *The second island has not pulled up the river towards it, as the first island did.* This is mainly due to the bela on which the second island was constructed being very high and the main stream situated at a great distance from the centre-line.

Effect of three pitched islands. A third pitched island similar to the second was constructed 6,000 ft. upstream of the second island. At this place the main river takes a turn towards the left. The river bed obtained after constructing the second island was not altered. The model was run for different stage of flow. All the necessary observations were taken during the course of the operation of the model and also after stopping the model.

The conditions of flow in a discharge of 80,000 cusecs are illustrated in Fig. 16. From this figure, the following points were indicated :—

1. The main river was attracted towards the third pitched island.
2. Some flow took place over the bela on the left side of the island.

Observations showed that a deep scour occurred at the nose of the third pitched island. After running flood discharges, the discharge on the model was gradually lowered and photographs were taken at 80,000, 20,000 and dry conditions, in order to locate the deep channel and the bela. This is illustrated in Fig. 17*.

Fig. 17* shows that there is a channel formation along the left side of the third island. On the right side of the island, however, there is a bela in this discharge. This bela on the right side continues down to the second island. At the second island the bela is high. On the left side of the second island, there is a small local loop formed. Besides this, the following observations were noted :—

1. A bela forms downstream of the third island at a large distance from the centre-line. This bela has formed as a result of channel formation being parallel to the centre-line downstream of Island No. 3, and has a tendency to choke up the original deep channel along the left bank.

2. An Island formed upstream of the nose of the left guide bank, and the main channel was situated at the first island. There was no channel formation at the second island.

In another experiment, the effect of shifting Island No. 2 towards the left, *i.e.*, towards the main stream was examined. Pitched Islands No. 3 and 1 were not moved. From the observations made it was shown that no satisfactory results were obtained.

Conclusions. The following conclusions can be derived :

1. Construction of the pitched island No. 2 has not yielded satisfactory results. This is due to the high bela on which the island is located and also to the fact that the main river is situated at a great distance from the centre-line.

2. The construction of the pitched Island No. 3 considerably helps in pulling the river towards the centre-line, but for the high bela at island No. 2 a straight channel from pitched Island No. 3 to pitched Island No. 1 might have been secured.

3. Shifting the pitched Island No. 2 for a distance of 600 ft. towards the left of the centre-line induces the formation of a continuous channel from pitched Island No. 3 to pitched Island No. 1. This continuous channel is, however, very shallow. The main river opposite Island No. 2 is still situated at the extreme left at a considerable distance from the island.

Study No. 3.

Determining the effect of constructing a series of pitched islands joined to each other and the main river by a leading cut.

The whole of the bela between the Lalu Gudar channel and the main river was moulded in sand and three islands were constructed on the centre-line of the weir, first at 7200 ft., second at 13,200 ft. and third at 19,400 ft. from the weir. A leading cut 75 ft. in width was made in the river bed from the river edge upstream of the third island to island No. 1. This is illustrated in Fig. 18*.

To record river levels, gauges were fixed in the leading cut upstream and downstream of pitched islands. The model was operated as before with different stages. After running one complete season, a detailed survey of the bed was taken and is shown in Fig. 19*.

Conclusions. The following conclusions are derived from this study.

1. Up to a river discharge of 20,000 to 30,000 cusecs no appreciable flow in the cut takes place.

2. The cut develops with river discharges from 40,000 to 80,000 cusecs.

3. Further development of the cut stops in river discharges above 90,000 to 1,00,000 cusecs. With these discharges flow takes place over the whole of the bela and the cut becomes sluggish.

4. In falling floods below 80,000 cusecs, flow takes place in the cut. The intensity of flow is, however, less than that obtained with the same discharge before the floods.

The alignment of the leading cut was slightly altered. Instead of making the leading cut on both sides of the island, the cut was made only on the left side. Running the model showed that the results were similar to those obtained with the original alignment.

Study No. 4.

Determining the effect of constructing a series of pitched islands joined to each other and the main river by a leading cut, the main river also closed by an earthern bund.

In this study, besides making a leading cut from the main river to the islands, the river was closed 150 ft. downstream of the mouth of the leading cut by an earthen bund. The top of the bund was fixed at the river level obtained with a discharge of 20,000 cusecs. The discharge equivalent to 1600 cusecs was run. The flow in the cut started. However, a considerable heading up took place at the bund.

Discharge was next increased to 1800 cusecs which resulted in further heading up at the bund. By increasing the discharge of the river to 2,000 cusecs, the bund was over-topped and then breached at R. D. 250 from the right bank, as illustrated in Fig 20.

Conclusions. The leading cut failed to develop even when the main river was closed by means of a bund. The water level obtained with a discharge of 2,000 cusecs with the bund in position was as high as that obtained in the river with a discharge of 20,000 cusecs. This method was shown to be unsuccessful.

Study No. 5.

Determining the effect of constructing a single pitched island close to the noses of the upstream guide banks.

It was decided to construct one pitched island on the prototype in the winter of 1943-44. The suitable position and the design of the island was required to be determined on the model. From the preliminary tests carried out, it was shown that on the 1943 November Survey, the most suitable position, if only one pitched island was to be constructed, was on the centre-line 4500 ft. above the weir. For detailed investigation the model for a length of five miles above weir was moulded to the 1943 river survey. One pitched island was constructed 4500 ft. above weir as shown in Fig. 21*. The design of the island is shown in Fig. 22. The model was run for different stages of flow and observations were made as before.

It was observed that no action took place at the island in low river stages due to the pond that had to be maintained for feeding the canal. In the medium river stages from 40,000 cusecs to 1,00,000 cusecs the island came into action. A view of the island in a discharge of 40,000 cusecs is shown in Fig. 21-A*. The scour developed at the nose of the island and the current had a tendency to move towards the centre-line. There was also a tendency of silting up above the nose of the left guide bank. The model was run for high flood discharges.

Conclusions. The following conclusions are obtained from this study. The most suitable position for a pitched island, if only one is to be constructed in 1944, is 4,500 ft. above the weir, on the centre-line.

2. There is a tendency of the main river to shift towards the pitched island. There is also a tendency of silting up near the nose of the left guide bank.

3. The tail end of the bela between the Lalu Gudar channel and the main river moves upstream.

When the island was made in small stones, it was shown that in a discharge of 80,000 cusecs the island collapsed. However, for the complete study the island was reconstructed and the model run. A fresh experiment was carried out to determine the effect of running the model in the presence of the collapsed island. It was shown that if the island collapsed, its effect to attract flow, channel and bela formation is lost. The scour previously formed, begins to fill up to a great extent when the model is run with flood discharges in the collapsed condition. It is, therefore, indicated that in order to straighten the river above the weir and to tie the deep channel on to the pitched island, the pitched island must be

strong enough to stand the flood discharges. If the pitched island collapses, the control over the river will be lost.

Study No. 6.

A comparison of the river conditions in the absence and in the presence of the pitched island constructed at 4,500 ft. above the weir.

In order to check the results obtained in the previous study with river conditions in the absence of the island, an experiment was carried out in which no island was constructed. The model was moulded as in other cases according to the November, 1943 Survey and run with the same discharges as used before. All the necessary observations were taken.

The main indications obtained are :—

1. That in the absence of the island the extent of the erosion of the left edge of the central bela was much less than that obtained in the presence of the island.

2. The main river did not shift towards the pitched island. No bela formed upstream of the nose of the guide bank. However, it may be pointed out that the attraction of the island was marked in the initial stages of flow and in the rising floods. In the falling floods there was tendency for silting at the island.

As a result of the above studies, it was shown that the construction of the pitched island proved to be very helpful in straightening the river course above the weir. Study No. 5 showed that above certain discharges, the pitched island might collapse. It was, therefore, considered necessary to investigate in detail the design of the pitched island on a large scale river model either non-distorted or much less distorted than used before.

Study No. 7.

An examination of the design of the pitched island on a large-scale model.

Accordingly, a part model of the River Sutlej above Suleimanki constructed to the following scales was examined :—

Horizontal Scale	Model to prototype	1/50
Verticle Scale	do	1/20
Grade of sand used		·44 mm.

The model represented the weir, the guide banks and the River Sutlej for a length of two miles above Suleimanki Weir. The pitched island was constructed at 4,500 ft. above weir in stone of 3 ins. to 6 ins. diameter. The apron, etc. were laid at levels according to the design shown in Fig. 22. Since the junction point of the two channels was situated five miles above the weir, two separate feeding arrangements for the Lalu Gudar and the main channels were made. The model was run with all the discharges used previously. The pond level maintained in the experiments was at R. L. 569 the same as used on the prototype in 1943.

Up to a discharge of 80,000 cusecs in the river the velocity of flow near the island was small. Some flow took place from the right channel

towards the left just over the apron of the upstream nose of the pitched island. The main flow which takes place along the left bank is illustrated in Fig 23.

In a discharge of 1,00,000 cusecs, the main flow occurred in the Lalu Gudar channel at 50—100 ft. from the right edge of the pitched island. The current in the main river had a tendency to flow along the left edge of the central bela and attacked the bela at 7500 and 5500 ft. above weir. At these points the erosion of the bela occurred. The current then took a course towards the centre and opposite the pitched island the main current was situated about 250 ft. from the left edge of the pitched island. No marked action occurred in the gap between the pitched island and the central bela in this discharge. In a discharge of 1,50,000, 1,75,000 and 2,00,000 cusecs the main current moved towards the pitched island, as illustrated in Fig. 23-A.

For comparison, the directions of flow in low discharges before floods are given in Fig. 23. The erosion of the central bela, as measured after running 2,00,000 cusecs was as below :—

Distance above weir.	*Depth of erosion.*
8500′ above weir	250′
7500′ ,,	100′
6500′ ,,	50′
5500′ ,,	100′
5400′ ,,	250′
4900′ ,,	200′
4650′ ,,	100′

The highest discharge run in this study was 2,75,000 cusecs. The velocities in the main river and the Lalu Gudar channel taken during different stages of the run are given in Table I. River gauges and the depth of scour near the pitched island are shown in Table II.

After running medium and low floods, the model was closed and a survey of the bed was taken. Photographs showing the bed conditions were also taken and are given as Figs. 24* and 24-A*, 29-B* and 25*. From an examination of the results obtained the following conclusions are drawn :—

1. No marked action takes place in the river discharges up to 1,00,000 cusecs.

2. As the river discharge rises above 1,00,000 cusecs, the pitched islands starts functioning. Upstream of the pitched island, the main river has a tendency to flow straight to the pitched island. An attack on the Central bela occurs at 7,500 and 5,500 ft. above the weir.

3. The velocities at the left edge of the island in the medium flood discharges are the highest. The deepest channel of the river moves towards the left edge of the island, in floods. However, in the falling flood discharges, some silting of the deep channel occurs.

4. The maximum scour at the pitched island obtained with pond at R. L. 569 is 22 ft. In the falling floods, however, it silts up about five to six feet.

5. Downstream of the pitched island, the deep channel exists in the centre.

6. In the Lalu Gudar channel also, the deepest scour occurs near the pitched island. The right half of this channel has a tendency to silt up.

From a perusal of the results obtained in the above studies, it will be seen that the construction of the pitched island helps considerably to straighten the river course above the weir. The pitched island attracts the river on to it and a deep channel forms there.

In the above studies, the pitched island was used for straightening the river course above the weir. The use of the island has been further extended to several other cases, such as :—

1. To obtain uniform distribution of flow between the guide banks during river diversion after the completion of the Headworks.

2. To reduce the action on the outside of a river curve.

3. To alter the course of hill torrents where they join the river.

4. To straighten the course of a river in the reach where no control points exist.

A brief account of the investigations mentioned above is given below :—

(*ii*) *1. The obtain uniform distribution of flow between the guide banks during river diversion after the completion of the headworks.—A study of the effect of construction of pitched islands on the River Indus upstream of the Glancy Barrage on distribution of flow between the guide banks.*

The River Indus after leaving the gorge above the North Western Railways line connecting Mari and Lahore divides into three channels. The right channel is the main river and the central and the left channels are subsidiary. The barrage is constructed on the left side of the central channel. The left channel is closed and the central channel is diverted to the main river for constructing the Barrage.

The barrage has been completed. The river may have to be diverted to the weir during the cold weather of 1944-45. The schemes to be adopted for the river diversion are examined on the model. The model studies show that after the diversion, the main river flows along the right guide bank instead of being distributed uniformly between the guide banks. A high bela forms along the left guide bank. The conditions of flow in a discharge of 70,000 cusecs after running the model for a period equivalent to one year after diversion show that no flow takes place in front of the left half of the weir in this discharge, and flow occurs parallel to the weir from the right to the left in order to feed the Thal Canal. This is natural since the river in the past few years has been flowing along the nose of the right guide bank, thus causing a very

deep scour there. In the last monsoon, a large quantity of stone has been dumped in to protect the nose from being washed away.

In order two obtain a uniform distribution of flow between the guide banks, two pitched islands, each 500 ft. in length were constructed on the model at positions shown in Fig. 26* and their effect during the period of diversion and in floods after diversion was examined. It was shown from the model results that the right hand pitched island came into action during the diversion period. Due to the presence of this island, the flow was directed towards the left and the channel along the right guide bank was less deep than that obtained in the absence of the islands.

The left hand pitched island did not come into action till floods. It helped to maintain the flow along the left guide bank.

Conclusions. 1. The river after diversion sticks to the right guide bank. A deep channel forms there. A shoal forms along the left guide bank.

2. The construction of the pitched island in the river bed upstream of the guide bank helps to distribute the flow between the guide banks. At least two pitched islands are required. The most satisfactory positions for these islands are as shown in Fig. 27*.

(iii) 2. To reduce the action on the outside of a river curve.—A study of the effect of construction of pitched islands near the left bank on the River Sutlej, 12 miles upstream of the Islam Headworks, on the action on the right bank opposite the islands.

The River Sutlej upstream of the Islam Weir has been eroding heavily the right bank opposite R. D. 55,000 of right retired embankment. The erosion was particularly severe after the cut-off which occurred at mile 7 in 1942. Fig. 34 illustrates the river course in 1943. Opposite R. D. 50,000 to 60,000 the deepest channel of the river is situated at the extreme right bank. It was feared that if the erosion of the right bank is allowed to continue, the right retired embankment may be washed away, thus outflanking the weir. In order to reduce the action on the right bank and to shift the deep channel from the right to the left, a pitched island was constructed on the model near the left bank at the position shown in Fig. 28*. At this place the bela is high and is over-topped only in floods. The model was run for a period equivalent to one year. Observations regarding current directions, velocity and scour at the island were made in all the important discharges. After running each flood discharge, the model was closed and a survey of the bed in the vicinity of the island and of the deep channel was made in order to determine the changes in the configuration of the bed due to the presence of the island.

The conditions of flow in a discharge of 75,030 cusecs are illustrated in Fig. 29*. The velocity observations and the soundings for important conditions are given in Fig. 28.*

The island did come into action. The main current which in the

absence of the island flowed on the extreme right, now became central. A deep scour hole occurred at the upstream nose of the island. This scour extended to a distance of 500 ft. downstream of the island. Near the island, the velocity of flow, was much higher than at any other point, in the flood discharges. However, one island, though effective was not capable of shifting the main channel from the right to the left. In order to secure this a series of islands was required.

A second pitched island 500 ft. downstream of the first was next constructed and the model was run for another year. The effect on the distribution of flow was determined. The conditions after the construction of two islands are illustrated in Fig. 29-A*. It was shown that a channel, though shallow, formed along the left bank. It appears that at least three islands may be required to shift the channel from the right to the left bank.

Conclusions. 1. The pitched islands constructed on a bela on the inside of a curve help to reduce the intensity of action on the outside of the curve.

2. Shifting the channel from the outside to the inside can only be secured by a series of islands.

(iv) 3. To alter the course of hill torrents where they join the river.—A study of the effect of construction of a pitched isand near the right bank of the River Ravi, on the course of the Manghar Hill Torrent downstream of the Madhopur Headworks and reducing action on the left bank at Bherian Spurs.

Downstream of the Madhopur Headworks, the River Ravi flows close to the Slampur Feeder. In the year 1936, the river eroded the left bank very severely and threatened to wash away the feeder. In order to protect the Slampur Feeder, a series of armoured spurs was constructed along the left bank. The construction of the spurs protected the left bank, against further erosion, but the spurs came under heavy action in high discharges.

Upstream of the Bherian Spurs, there exists a torrent known as Manghar. During the monsoon, the flow from the torrent strikes the main river and deflects it towards the left, which causes action at the spurs. If the flow from the torrent did not hit the main river, it might distribute itself uniformly instead of concentrating along the left bank.

In order to secure this, the effect of the construction of a pitched island at the point where the torrent flow joined the main river was investigated by means of models. A pitched island at position shown in Fig. 30* was constructed. Running the model for a period equivalent to one year showed that the discharge from the torrent, instead of going towards the left, flowed near the pitched island and a channel, though shallow, formed there. A slight amount of silting occurred at the Bherian Spurs. However, for complete success, it is necessary to run the model for a number of years. The effect of the pitched island on shingle bed is much slower than that obtained when the island is constructed on an alluvial bed.

Conclusions. 1. A pitched island helps to divert the flow from a torrent away from the main river ; thus avoiding concentration of flow.

2. The action of the pitched island on the shingle bed is much slower than that obtained when the island is constructed on the alluvial bed.

(v) 4. To straighten the course of a river in the reach where no control points exist.—A study of the effect of construction of pitched islands on the River Beas near the Western Bein.

In the previous studies, experiments were made on the reaches of a river in the vicinity of a weir or a barrage. In continuation, the effect of pitched islands in straightening the portion of the river where no such control points exist was investigated.

The River Beas in the northern corner of the Bist Doab has been eroding its left bank very heavily. The seriousness of the situation was due to the fact that very close to the left bank of the River Beas, exists a natural drainage of the country known as the Western Bein. Water level in the Western Bein is about 10 ft. lower than the high flood level in the river. If the river breaches the left bank, it will flow into the Bein and may cause disaster to the Railway line, the G. T. Road, and a part of Kapurthala State.

In order to protect the left bank from further erosion, three armoured spurs were constructed. The spurs worked satisfactorily for two years, *i.e.*, 1940 and 1941. In 1942 unprecedented high floods were experienced in the river, which caused damage to the spurs. It was decided not to repair these spurs and to construct a collapsible spur on the right bank downstream of Spur No. 3. The spur was designed by Mr. Inglis. The construction of the spur did not help to attract the river towards the right bank.

A series of pitched islands was next constructed and their effect examined. In this case, an attempt was made to pitch the nose of a natural bela in the river bed with stones, as illustrated in Fig. 31*. In the first case, one island was constructed and the model run for a period equivalent to one year. Next year, another island was constructed downstream of the first island and the model again run for a year. Third year, another pitched island was added, and the model was run for another year. After the three islands were constructed in position, the model was run for a period equivalent to two years more. Experiment showed that the construction of three islands helped to straighten the river. The islands had to be constructed one by one.

Conclusions. 1. The construction of the island helps to straighten the river in a river reach not provided with control points. However, it takes much longer time and a number of pitched islands are required to straighten the river course.

2. Pitching the nose of the natural bela in the river bed proves to be a very satisfactory method.

A STUDY OF THE PITCHED ISLAND BY MEANS OF FULL SCALE EXPERIMENTS

Effect of a pitched island constructed on the River Sutlej above Suleimanki Headworks, S. V. P:—Encouraged by the results obtained from the model experiments, it was decided to construct one pitched island on the prototype and carry out full-scale experiments.

Selection of the site for the pitched island. From the model studies, the most suitable site for the construction of one pitched island was shown to be on the centre-line to the weir downstream of the tail end of the central bela, separating the main river and the Lalu Gudar channel. The advantages of this site were as follows :—

1. At this position, there was a likelihood of the pitched island coming into action from both the sides due to the flow in the main river and the Lalu Gudar channel.

2. At this position, the river regulation at the weir influenced the working of the island. This is very important, since the nearness of the island to a control point is very essential for the efficient working of the island.

The upstream nose of the pitched island had to be located at R. D. 4617 from the weir. During the construction, however, the alignment was slightly altered and the island was moved 40 ft. towards the left of the centre-line.

Design of the pitched island. The design of the pitched island finally adopted for construction is shown in Fig. 22.

The main features of the design are :—

1.	The upstream nose	...	Semi-circular.
2.	Downstream	...	Fish-tail.
3.	Length of the island at the top		197 ft., the top width being 50 ft.
4.	Length at the bottom	...	352 ft.
5.	Side slopes	...	2 to 1.
6.	Length of the apron	...	40 ft. (the thickness varying from 4 to 7 ft. from the toe to the end.

The top level of the island was kept at R. L. 579. The water level during the highest flood discharge ever recorded at this place was found to be L. R. 576. A free board of 3 ft. was kept.

Construction. The island was constructed in January, 1944, in the annual closure. It was built in stone approximately of man's weight and hand pitched. The cost of the island was Rs. 1,08,000 Fig. 32* gives a view of the completed island.

River conditions in February, 1944—just after the construction of the island. A

detailed survey of the river bed was made in February, 1944, in order to determine the conditions of channels and belas existing at the time of the construction of the island and to compare these with the river conditions observed later on, as a result of the effect of the island. For this purpose river sections 250 ft. apart for a length of 1,000 ft. upstream and 2,000 ft. downstream of the pitched island were taken in the main river and the Lalu Gudar Channel. A contour survey of the bed in this reach is shown in Fig. 33*.

From a study of Fig. 33*, it will be seen that :—

1. Upstream of the pitched island, the deep channel is situated along the left bank. Opposite the pitched island and downstream of it, the main river channel continues along the left bank. At the nose of the upstream left guide bank, there is a very deep scour hole. Downstream of the nose, the deep channel continues along the left guide bank for some distance. The channel then moves towards the centre of the weir. From the left bank of the main river towards the left edge of the central bela, there is a continuous rising of the bed level.

2. The deepest part of the right channel is situated at a short distance from the right edge of the central bela.

3. Downstream of the pitched island there is a bela which continues up to R. D. 3,000.

4. The central bela is 160 ft. in width just upstream of the island and is 890 ft. further above. The top of the bela is approximately at an average level of 568·8

Composition of the central bela and the main river. In order to determine the composition of the bela, samples were taken at various depths and analysed. The size distribution curves of samples obtained from different depths are given in Fig. 34*.

From an examination of the size distribution curves it is shown that the top two ft. of the bela consists of material mostly clay and medium silt ; 2 ft. below the top, there is a layer of clay, 1 ft. in thickness. Below the clay strata the bela constitutes mostly of medium sand with a certain percentage of coarse material. Eight and ten feet below the top of the bela, the material consists mostly of coarse sand. It is, therefore, clear that the top 3 ft. consists of tenacious clay and below that, the bela is composed of material which is erodible.

A sample of silt was also taken from the bed of the main channel, near the pitched island. From the analysis it was shown that the material consists mostly of medium silt with a little percentage of clay. The composition of the bed material was approximately the same as that of the material at the foundation levels of the pitched island. The size distribution curve is given in Fig. 34*.

Programme of observations to be carried out on pitched island during Monsoon 1944. In order to determine the working of the island in detail the following programme of observations was framed for the Monsoon season.

1. **Current directions above and below the pitched island.** To record the alteration in river approach to the island and the direction of flow downstream of the island and between the guide banks, it was decided to observe current directions. In low discharges, the current directions were to be recorded with the help of the photographic camera using dried cow-dung-cakes to indicate the flow lines. In high discharges, however, instead of using cow-dung-cakes, lighted floats were to be used. The operation was to be performed at night and the photographic plate was to be doubly exposed.

2. **Velocity observations.** The velocity observations were to be made at the upstream nose and the sides of the pitched island and in both the channels opposite the pitched island.

3. **Scour and silt observations at the pitched island and in the main river and the Lalu Gudar channel.** The scour odservations in the channels were to be made every fortnight at important sections and monthly at other places. The observations at the island were to be made in all important discharges as far as possible.

4. **Action on the apron of the pitched island.** Observations were to be made to find out the condition of the apron, in order to see if any settlement of the stones occurred.

5. **Erosion of the central bela.** Measurements were to be taken for determining the depth of erosion of the bela.

River discharges during Monsoon 1944. Before describing the observations made and discussing the results obtained, it is necessary to make a brief mention of the river conditions experienced during this monsoon.

The river remained exceptionally low this year. Up to the end of June, 1944, the maximum river discharge at Suleimanki was about 12,000 cusecs and no winter freshets were experienced. In the month of July also, there were few medium floods. The maximum discharge experienced in this month was about 1,00,000 cusecs. Throughout August, with the exception of 7th—9th and 13th, the river was below 1,00,000 cusecs. The maximum discharge experienced during this year was 2,05,000 cusecs. In the last week of the month, the average discharge in the river was 50,000 cusecs. The first week of September experienced a medium flood of 1,50,000 cusecs. After this the river fell suddenly.

It will be seen that the year 1944 was an exceptionally low river year compared with 1942 or 1943. In 1942, the highest discharge experienced was 3,25,000 cusecs. For about 35 days during the Monsoon the discharge in the river was above 1,00,000 cusecs. There were several floods above 2,00,000 cusecs.

The Observations made. Efforts were made to adhere to the programme of observations mentioned above, but it was not possible to follow it rigidly. The local officers intimated that in discharges above 1,50,000 cusecs observations could not be made safely. For making observations in discharge of 1,25,000 to 1,50,000 cusecs a motor launch had to be used.

Since the petrol for the launch was not available the observations in these discharges also could not be made.

In all, six complete sets of observations were made during the monsoon season. The dates on which these observations were made are given below :—

1. June 15.
2. July 6 and 22.
3. August 9, 10 and 11.
4. September 2, 3, 4 and 12.

Plottings of the Observations. The data obtained for each date is plotted on a separate sheet. On each sheet, observations of the river bed taken just after the construction of the pitched island are also given. This gives, at a glance, the progress of scour and silting. The depth of the erosion of the central bela is also shown.

Information regarding river discharge, regulation and pond levels for each set of observations is also given in each sheet.

Photographs. Photographs of the river conditions and the action on the island at different stages of the flow were taken and would be referred to during the discussion of the results.

Discussion of the Results. Each set of observations is examined separately and discussed by months.

June 1944

Fig 35* shows the plottings of the observations made on 15th June, 1944. From an examination of this figure, it will be seen that a definite alteration took place in the river approach to the island. Section A which is 300 ft. above the upstream nose of the island shows a scour of 10—12 ft. in a length of 400 ft. from the left edge of the central bela. At the left bank of the main channel, however, there is some silting up.

Section B, which is at the upstream nose of the pitched island also shows scouring action upstream of the pitched island and silting on the left side of the main channel. The scour in the two sections upstream of the pitched island definitely indicates the river being attracted towards the island, and consequently a definite change in the approach. Sections A1, B1 and C1 show the same tendency, as exhibited by A and B. Section C does not record any marked change. Section D shows a slight scouring action in the centre and a silting up on the left side of the main channel. Section E shows a scouring action throughout the width of the river. Section F indicates a scouring action on the right side of the centre-line, while silting up at the left guide bank.

Deep channel moves from left bank to the island and left channel silts up. From a perusal of the above account, it will be seen that there has been a considerable change in the river approach. The river has been attracted towards the pitched island and silting along the left bank and