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HYDRAULIC RESEARCH STATION, MALIKPUR

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THE HYDRAULIC RESEARCH STATION, MALIKPUR.

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INTRODUCTION.

The importance of Hydraulic Research as an aid to the Engineer in arriving at suitable designs for irrigation works is now well recognised. In Europe and United States of America, large Hydraulic Laboratories are maintained, where designs, of works are investigated by means of models before construction. Similarly, any improvements introduced on existing works are first tested in the laboratories. The Punjab maintains the Irrigation Research Institute for carrying out research work on different types of irrigation problems.

The Hydraulic Section of the Irrigation Research Institute consists of :—

1. Two Hydraulic Laboratories, equipped with glass flumes, glass tanks, river trays and a tilting flume, where models of works to small scales are investigated.
2. A Research Station at Malikpur where large scale models are investigated.
3. Outlet Research Station at Joyanwala where different types of outlets are studied with a view to evolve a most suitable design.

The object of this Paper is to give an account of the Malikpur Research Station, the facilities available, the type of work carried out and some of the results obtained with their application to the prototype. Verification of model results from observations on the prototype will be discussed. A brief mention will also be made of savings effected as a result of model experiments.

II. DETAILS OF THE RESEARCH STATION.

1. The Malikpur Hydraulic Research Station is situated on the left bank of the Upper Bari Doab Canal, Main Line, between Miles 5 and 7 from the Madhopur Headworks. The main advantage of the site is that water supply from the canal is available for over eleven months a year.

The Station was started by Mr. Haigh in 1925, when a small outlet above Rapid No. 12 of the Upper Bari Doab Canal, Main Line, was constructed. A masonry flume and a measuring tank were built for carrying out certain experiments. Experiments on weir co-efficients were carried out in the flume but after Mr. Haigh left the Gurdaspur Division, no development took place till 1936. In that year large scale models of flumed falls in the Nili Bar Circle were examined[1] for investigating methods for reducing bed scour and side erosin.

1. In the year 1937-38 experiments in connection with the Haveli Project were carried out at Malikpur for R. B. Kanwar Sain, the then

1. A study of methods of protection below falls in the Nili Bar Circle by Harbans Lal Uppal, M.Sc., Ph.D. and Nazir Ahmad, M.Sc., April 1937 (Type-written).

Director, Central Designs. A model[1] of the River Jhelum and Chenab downstream of their confluence and a part model[2] of the Emerson Barrage, were examined. Different types of falls to be constructed in the Haveli Main Line were also investigated. After the completion of the Haveli Experiments no development of the Station took place for a year and a half.

During the past five years, however, the Station has expanded very considerably. The total area of the Research Station now is over 100 acres consisting of a rectangular strip of land 5,000 feet in length and 1,000 feet in width. The country slopes from North to South and from West to East. This natural slope of the country is of great help in constructing models cheaply and quickly since the models run from North to South and the supply channels for the models from West to East.

The total discharge available for use on the models is about 700 cusecs. This is taken from three regulators situated at different points along the length of the Station. The total head of water at the lower end of the Station from the regulator at Rapid No. 9 is 50 feet.

The Station is electric connected. There are motorable roads on the Station leading to various models. Important points are connected with telephone.

For an easy access to the material quarries a scheme of laying a tram line for a length of about four miles is in hand.

Quarters for the whole of the staff working on the Station have been sanctioned. The construction will be taken in hand shortly.

2. The Lay-out of the Station. The lay-out of the station is shown in Fig. 1. The area is divided into a series of trays and flumes of varying sizes in order to accommodate different models for investigation. A brief description is given below :—

There are three head regulators for obtaining water for the Research Station. The first two regulators take off the Main Line above Rapid No. 12. The third regulator is constructed above Rapid No. 9 at the head of the Farida Nagar Feeder. A parent channel runs from North to South parallel to the canal bank and at convenient points supply channels are taken off. There are six supply channels, each 25 feet wide, provided with gates at the head to regulate the supply.

Along the eastern boundary of the Station runs a natural escape which receives the water of all the supply channels after use in the models. This escape channel then joins the Upper Bari Doab Canal at

1. Experiments for the Haveli Project on a model of the Rivers Jhelum and Chenab downstream of their confluence by N. K. Bose, M.Sc., Ph.D., Mathematical Officer, and L. Thakar Das Gulati, M.Sc, Research Assistant, Research Publication, Vol. II, No. 24.

2. Experiments for Silt control on a model of the Emerson Barrage, left undersluices, left regulator with a part of the River Chenab upstream, by N. K. Bose, M.Sc., Ph.D., Mathematical Officer, and L. Thakar Dass Gulati, M.Sc., Research Assistant, Research Publication Vol. II. No. 25.

the end of the southern boundary of the Station. Practically no wastage of canal water takes place due to the Station.

3. Trays for constructing models of Rivers, etc. There is a large number of trays of varying sizes for constructing models of rivers, canals, level crossings, etc.

The river models are constructed in large trays while models of other works such as regulators, level crossings and silt ejectors which require only a short length to be represented are fitted in small trays.

Each tray is connected to its supply channel through an approach flume about 10 feet wide and 50 feet in length. At the end of each approach flume a sharp-crested weir is constructed for measuring the discharge used in the tray for running the model. Upstream of the sharp-crested weir smooth flow is obtained by constructing a series of honey-combs. In order to aerate the nappe, a G. I pipe, 1·5″ diameter is fitted below the crest. A gauge well is constructed upstream of the sharp crested weir at a distance of eight times the depth of water at the crest for measuring the head of water over the weir. The approach flume downstream of the weir diverges towards the commencement of the model.

For each tray there is also an exit flume which delivers water after use in the model to the downstream supply channel. The flumes are usually earthen while the outfalls into the supply channel are made pacca.

4. Flumes for constructing models of Falls, Rapids, Bridges, Regulators, etc. There are a number of main flumes, masonry, earthen and flumes with shingle bed. A brief description of each is given below :—

(*i*) *The Masonry Flume.* The masonry flume is 170 feet long, 8 feet wide and 6 feet deep. At the upstream end of the flume a sharp-crested weir is fitted with a gauge well on each side 10 feet upstream of the weir. The central portion for a length of 40 feet is fitted with straight-edges. A trolly provided with a pointer gauge and a pitot tube runs over the straight edges. A model of a section of a weir or a fall, required to be examined, is fitted in this portion of the flume so that detailed observations could be made. The sides of the flume where the model is fitted are painted in duco-white and are graduated so that the exact point of the formation of the standing wave, etc., could be recorded. At the downstream end of the flume a rising gate is provided to control the water level in the flume. Downstream of the gate the flume is connected to the measuring tanks through a diversion valve arrangement. A view of the flume is given in Fig. 2.

(*ii*) *Earthen Flumes.* There are five main earthen flumes fitted with measuring weirs and control gates for investigating complete models of canal works. The earthen sides of the flume serve as the earthen banks of the channels below the works on the model. The flumes are of different sizes each suited for a particular type of investigation.

The first flume is 20 feet wide, 3 feet deep and 150 feet long. Models of falls, bridges and regulators in the Main Lines of canals are examined in this flume for side erosion and wave lap.

The second flume is 15 feet wide, 4 feet deep and 250 feet long. Models of falls and bridges in the branches are investigated in this flume.

The third flume is 25 feet wide, 4 feet deep and 200 feet long. The flume is reserved for the study of side splays and bowing.

The fourth flume is a small one, 10 feet wide, 2 ft. deep and 100 feet long. This is used for models of small works.

The fifth flume 400 feet long and 10 feet wide with a large drop between the upstream and downstream ends is used for examining alternative designs of falls constructed one above the other. At least three models can be simultaneously investigated in this flume.

(*iii*) *Flumes with shingle bed*. There are two large flumes with shingle bed for the investigation of models of rapids. A view of a portion of one of the flumes is given in Fig. 3.

5. Tanks for Volumetric Measurements. There are two tanks fitted with pointer gauges and sluice valves for the volumetric measurement of discharge. The tanks are connected to the masonry flume through a diversion valve arrangement. The arrangement is instantaneous and leak-tight. Till the conditions of flow in the flume are steady, the flume is connected to the escape channel. When the flow is established, water in the flume is diverted to the measuring tanks, the time of diversion being recorded either by half a second chronograph or a stop watch.

III. APPARATUS.

The Station is equipped with the following apparatus :—

1. Pointer gauges reading up to 1/1,000 and 1/2,500 of a foot are used for the measurement of water surface and bed levels. There are also gauges fitted with micro-am-meter. The contact of the water surface with the pointer is indicated by the deflection of the micro-am-meter. This arrangement is of considerable help in the accurate measurement of water surface level in the gauge wells especially for taking observations during night.

2. **Pitot tubes**. There are several types of pitot tubes for recording the velocity of flow of water on the model. The Prandtl type pitot tubes fitted with water and mercury manometers are used for general work. The Gallenkemp Industrial type pitot tubes are used for measuring high velocities. There are also Universal type pitot tubes for recording velocity of flow of water in different directions. Besides measuring the velocity, this apparatus is very useful in determining the direction of maximum velocity. Benzl tubes are used for measuring large velocities.

3. **Current Meters**. There are a number of Gurley type current meters at the Station.

4. **Theodolites and Levelling instruments.** For laying out the models there are a number of levelling instruments and theodolites.

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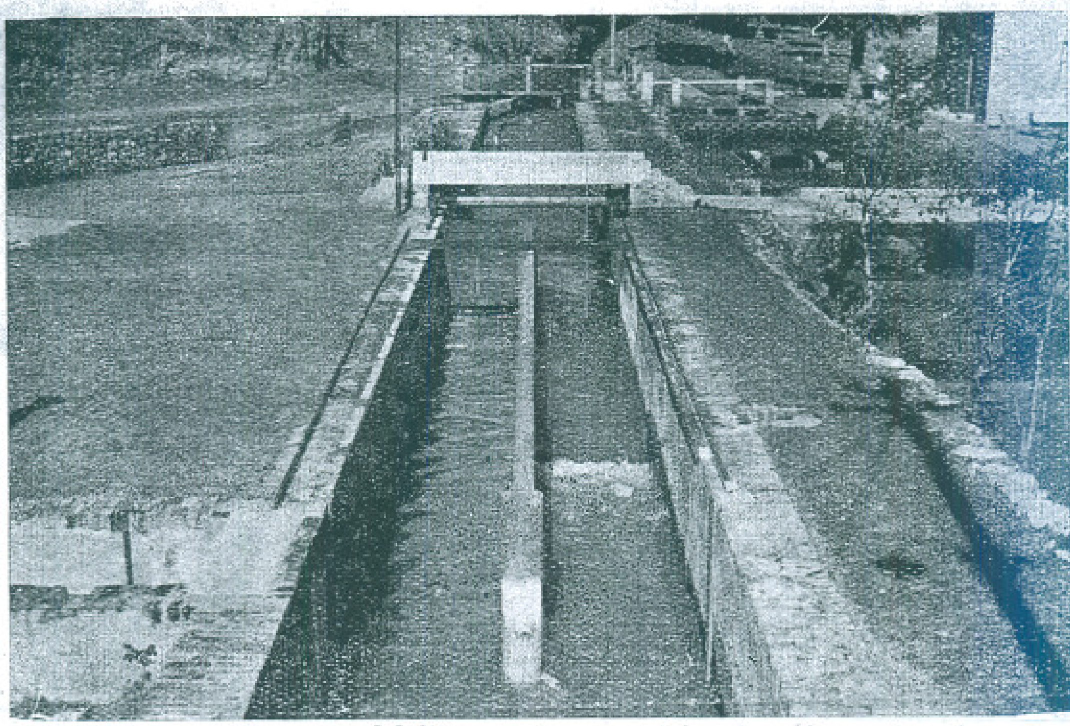
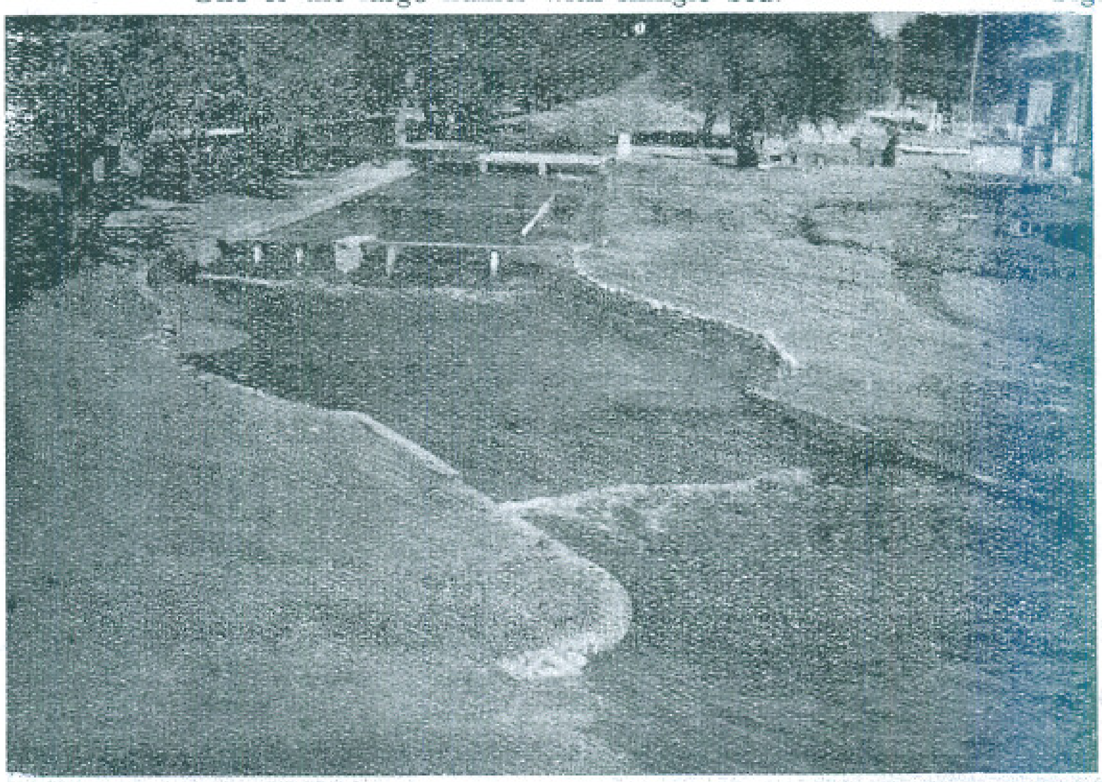
The Masonry Flume.

Fig. 2.



The Masonry Flume at Malikpur where models of sections of weirs are examined. The flume is 170 ft. long, 8 ft. wide and 6 ft. deep. It is fitted with straight edges over which a point gauge fitted on a sliding carriage, moves.

One of the large flumes with shingle bed. Fig. 3.



This photograph shows a view of the flume for investigating models of Falls and Rapids. The flume is 200 ft. in length and 30 ft. wide. Alternative designs of Falls and Rapids are examined in the flume.

5. **Electric Chronograph**. The apparatus is used for automatic record of time and is extremely useful for work in connection with the calibration of Meters and Flumes.

6. **Automatic Silt Feeders.** For adding silt to the river models during operation automatic silt feeders are used.

7. **Silt Sampler**. Samplers are used for determining the suspended and the bed silt on the models.

(*a*) *Suspended Silt Samplers*. For suspended silt, the Bottle and Uppal Samplers[1] are available. Occasionally Binkley Sampler is also used.

(*b*) *Rolling Silt Samplers*. For rolling silt Bose and Uppal Samplers are employed.

8. **Siltometer**. For determining accurately grades of silt used on the model Puri and Uppal Siltometers are available. The latter is both electric and hand driven.

9. **Apparatus for grading material**. A modified Uppal Siltometer is used for obtaining different grades of materials in large quantities.

10. **Photographic Apparatus**. In order to illustrate the various stages of flow during the operation of a model a series of photographs both still and moving are taken. Different types of cameras are available. A Cirkuit Camera for taking complete panoramic view of large models is also available. A library of cine films is maintained at the station.

11. **Current Direction Finders**. There are current direction finders consisting of blades fitted at the lower end of a G. I. Pipe. At the top end of the pipe a dial with an indicator is provided.

A new[2] method is used for taking current directions. The apparatus employed and the procedure adopted is very simple. It consists of exposing the same photographic plate twice. The operation is divided into two parts.

(*i*) Taking a basic photograph.

(*ii*) Taking the final photograph.

Taking a basic photograph. A photograph of the reach where the directions of flow are to be traced is taken in the day time, taking care that the masonry structures and the bifurcation points do not become over-exposed. The exposed plate is not removed from the camera which is kept in the original position till it is dark.

Taking the final photograph. When it is dark the shutter of the camera is completely opened and the final photograph is taken. A small kerosene oil lamp with a chimney mounted on $3'' \times 3''$ wooden base, as a float, is

1. An improved form of Uppal Sampler for determining suspended and rolling silt in a stream of water by Harbans Lal Uppal, M.Sc., Ph.D. (Abst. No. 9, Bull No. 41) C. B. I. Meeting, July, 1943.

2. A new method of determining the directions of flow in rivers and canals, by Harbans Lal Uppal, M.Sc., Ph.D.

put into the stream at a selected point. The shutter of the camera is kept open all the time the floats are in view. The whole operation takes about 8—10 minutes. A complete path of each float in the form of a continuous white line appears on the photograph. This is shown in Fig. 4. The method has also been used successfully for taking current directions on the prototype. On the prototype, however, in place of small lamps, floats consisting of 6″×6″ wooden plate with a 3″ wooden peg in the centre are used. Waste cotton dipped in a mixture of kerosene and vegetable oil is wrapped round the pegs on the plate. The cotton is lighted and the floats are put into the river. The current directions taken at one of the sites are shown in Fig. 4-A. Similarly the directions of flow at various depths can also be determined by fixing the wooden plates to weighted rods like velocity rods.

IV. THE WORK CARRIED OUT AT MALIKPUR IS DIVIDED INTO DIFFERENT TYPES.

River Investigations.

(*i*) River Diversion, Training, Regulation and Meandering.

(*ii*) River Bank Protection.

(*iii*) The optimum length and position of a divide wall in an under-sluices pocket for silt entry into the Canal.

(*iv*) Exclusion of shingle and silt, carried by the rivers from the Canals.

(*v*) Protection below Weirs and undersluices.

(*vi*) Design of Weir Profile.

(*vii*) Co-efficient of Weirs.

2. *Investigations for Canal Works.*

(*viii*) Design of Canal Falls, Bridges, Regulators, Rapids and level crossings.

(*ix*) Protection against bed scour and side erosion below Canal Falls.

(*x*) Design of Piers.

(*xi*) Design of Silt and Shingle ejectors.

(*xii*) Optimum shape of outfall channels of ejectors for the transport of silt and shingle.

3. *Investigation for outlets.*

(*xiii*) Co-efficient of discharge and silt draw of Hume pipe outlets.

(*xiv*) The influence of the angle of offtake on the parent channel.

4. *General Investigations.*

(*xv*) Calibration of meter, notches and falls.

(*xvi*) The influence of the grade of materials constituting the bed on the scour downstream of masonry works.

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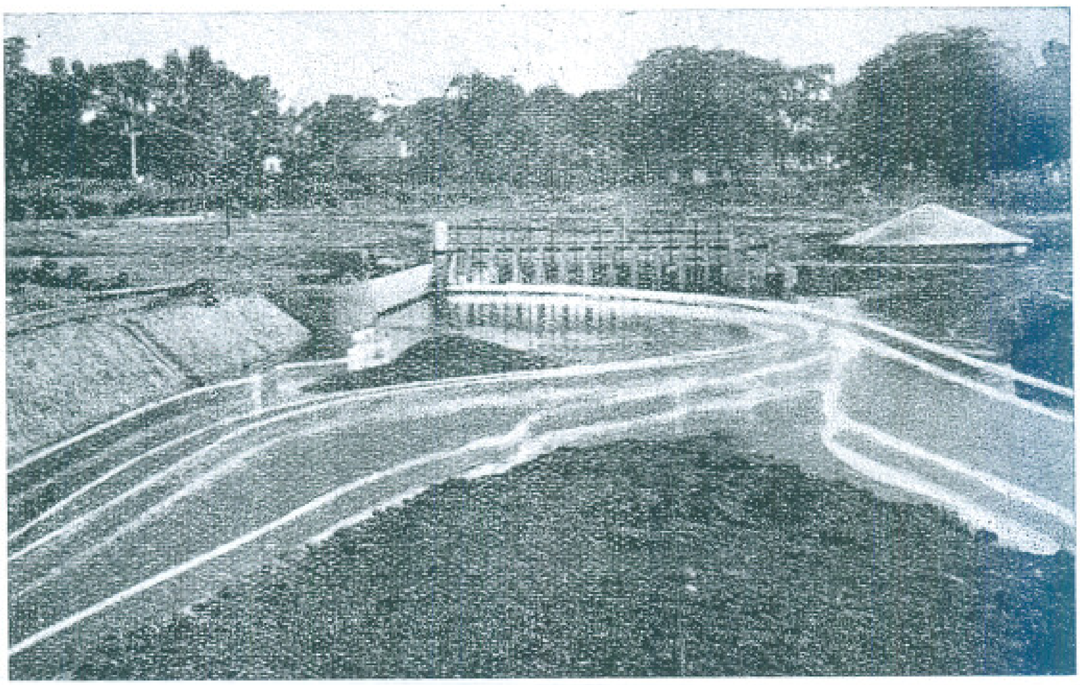
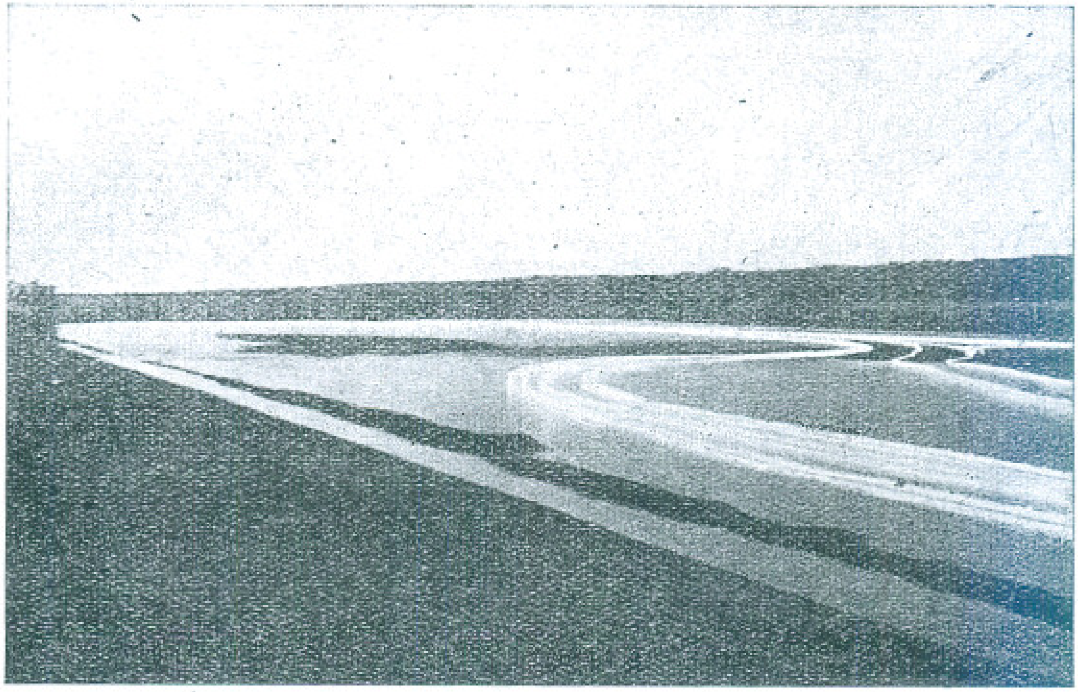
Current directions by the new method.

Fig. 4.



The current directions on the Madhopur Pocket Model as taken by the new method. The photograph shows the conditions in the month of November 1940.

Fig. 4-A.



Current directions on the prototype in November 1940 as taken by the new method.

(*xvii*) The influence of period of run on the depth of bed scour.

(*xviii*) The study of the phenomena of wave lap and investigations of methods to reduce it.

(*xix*) Capacity of lined and unlined channels for the transportation of silt.

(*xx*) Investigations for determining suitable scales for models of different types of works.

(*xxi*) A Study of Standing Wave and allied problems.

V. METHODS OF INVESTIGATION.

Methods employed for investigating different problems are different. The river problems require methods different from those employed in investigating problems on canals and other works. Similarly the method of construction of the models and the technique of experimentation adopted in the two cases are also different.

In case of river problems models of rivers with shingle and boulder bed require a different technique than that used for models of rivers with a sand bed. The bed material on the model in the case of shingle and boulder bed river is graded very carefully after a detailed examination of the movement of the bed with varying discharges. This aspect of the problem has been studied and has formed the subject of a separate Paper[1]. A brief account of the methods employed for investigating different types of problems is given below :—

A. Methods employed for the investigation of River Problems.

1. The Data. When a problem on a river with an alluvial bed is received for examination, the data required in connection with the investigation is obtained from the local officers. The following is some of the essential data required :—

(*a*) River survey plans for different years.

(*b*) River Sections and spot levels of certain important belas.

(*c*) Daily River Discharges.

(*d*) River gauges.

(*e*) Regulation diagrams at control points.

(*f*) Samples of material constituting the bed, belas and the banks.

In cases where no data is available, arrangements are made to collect the data on the above lines. When fresh data is to be collected the following points should be borne in mind.

(*i*) The river sections should be taken with reference to a certain fixed line. It has been observed that this point is often ignored and sections are taken at random. River surveys carried out without any reference line are of no value in the construction of models.

1. Methods of fixation of bed material for river models on shingle and boulder bed by Harbans Lal Uppal, M.Sc., Ph.D. (Type-written).

(*ii*) The plane-tabling should be made carefully so that the positions of channels and the belas agree with those shown by the river sections.

(*iii*) The river survey should cover the complete loops of the river.

(*iv*) Gauges should be erected at suitable points and recorded regularly.

2. Examination of the Data. An examination of the river survey plans for the past few years is made with special reference to the reach of the river under investigation.

3. Inspection of the Site. After a preliminary examination of the data an inspection of the site is made in order to study the local conditions.

4. The selection of the stretch of the river to be examined on the model. The next point to decide is the stretch of the river to be represented on the model. The following points should be taken into consideration in deciding this :—

(*i*) The length of the river selected for model tests should include not only the river portion at which trouble has been experienced but an appreciable distance up and downstream of it.

(*ii*) The entire river area between the marginal bunds and a short distance beyond these should be represented on the model. It is essential to construct all the river creeks on the model even those which are not live at the time of the investigation, since at some future time these may develop and if they are not incorporated on the model, the model tests may be of little value. It is also essential to reproduce all the creeks and the belas between the marginal bunds, in order to obtain correct water level during the floods. The water on the prototype in floods spreads over a considerable area. The corresponding area has to be provided on the model in order to simulate the true conditions.

(*iii*) If possible the upstream end of the river length selected should be such that the river there flows in one channel.

(*iv*) The length of the river selected should be such that it should include gauge sites and if possible one or more control points.

5. Selection of Model Scales. Having selected the river length to be examined on the model, the next point is to fix the model scales. It is not possible to go into great detail here, only the essential points regarding the selection of the model scales[1] would be mentioned.

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1. *Investigation of Model Scales,* Part I. Scales for rigid models, by Dr. Harbans Lal Uppal, M.Sc., Ph.D.

Investigation of Model Scales, Part II. Scales for river models, by Dr. Harbans Lal Uppal, M.Sc., Ph.D.

For the river models the scales to be fixed are :—

(*a*) The Horizontal Scale.
(*b*) The Lateral Scale.
(*c*) The Vertical Scale.
(*d*) The Discharge Scale.
(*e*) The Time Scale.
(*f*) The Silt Scale.

The first two scales are fixed and the remaining four are determined experimentally. The horizontal and the lateral scales used at Malikpur are the same.

(*a and b*) **The Horizontal Scale.** The following points should be kept in view in fixing the Horizontal Scale :—

(*i*) Since, the horizontal scale is the same as the lateral scale, the scale selected should be such that the width of different creeks of the river could be represented satisfactorily.

(*ii*) The horizontal scale, for models required for the examination of leading cuts and river diversion in low stages, should be such that the minimum widths of the cuts to be adopted on the prototype can be well represented on the model. For instance if the horizontal scale selected is 1/600 and if it is required to investigate the effect of a leading cut 50 feet on the prototype it would be impossible since the width of the cut on the model will be too small to allow any accurate observations to be made. Similarly in river diversion experiments the model discharge corresponding to the minimum discharge on the prototype with which the diversion is to be carried out should be measurable and effective. As the horizontal scale governs the discharge scale, the scale selected should be such that the model discharges corresponding to low river stages on the prototype are effective.

(*iii*) The scale selected should be such that the whole of the area, under investigation and also for a certain distance beyond this can be represented in a given tray.

(*c*) **The Vertical Scale**. For the river models the vertical scale used is usually much larger than the horizontal scale, since the depth of the river is very small as compared to the length or width of the river represented on the model. Now, if the vertical scale adopted is the same as the horizontal scale and if a long reach of the river is to be examined, the model will not represent correct conditions of flow as the depth on the model would be insignificant. The geometrical similarity has to be sacrificed in order to obtain hydrodynamic similarity. In certain cases, however, geometrical similar models with only a slight exaggeration of the vertical scale have to be used. In such cases a complete and a part model are examined. The part model represents short lengths of the river and is constructed either to a geometrical scale or to a slightly exaggerated vertical scale. At Malikpur the problem is first examined on a complete model with the vertical scale exaggerated and then in detail on a large part model.

The part models, constructed to a much larger scale than the complete models, are employed in certain cases for confirming certain important indications obtained on the complete model. In certain cases, however, a pilot model to a small scale is also used.

The following are some of the essential points to be borne in mind, in fixing the vertical scale :—

(*i*) The depth of the various creeks on the model should be well represented.

(*ii*) The scale selected should be such that the lowest equivalent discharge on the model gives turbulent conditions of flow and the Reynold's numbers are very large.

(*iii*) Where bank erosion is to be examined, the velocity of flow on the model should be sufficient to cause bank erosion.

(*iv*) The scale selected should be such that the general movement of the bed material on the model is reproduced with corresponding model discharges.

For a given horizontal scale the vertical scale can be roughly worked out with the help of one of the following mathematical formulae.

$d = l^{0{\cdot}75}$ for Manning's formula.

$l^{0{\cdot}65} 7d\ 7l^{0{\cdot}75}$ for Kutter's formula.

$d = l^{{\cdot}728}$ for Winkel's formula.

$d = f\,l^{0{\cdot}67}$ for Lacey's formula.

Where d is the vertical scale, l the horizontal scale and f the silt factor. However, the results obtained from these formulae differ appreciably from one another and they cannot be accurate guides.

The procedure adopted at Malikpur in case of certain models especially for the shingle bed models, is that the vertical scale is experimentally determined by temporarily constructing control works to different scales. The various vertical scales are then examined on the model with a particular bed material to arrive at the one which gives general movement of the bed on the model with the model discharge corresponding to the prototype discharge at which movement occurs at site. This method of determining the vertical scale is very satisfactory.

Tilt. Krey and others besides exaggerating the vertical scale of their river models have also used additional tilt in order to secure greater movement of the bed. The whole model is tilted thus giving an extra slope to the bed. The question of tilt has been examined in detail at

Malikpur. Tilt was first adopted on a geometrical similar model of the River Chenab at Khanki Headworks constructed to a scale of 1/50 and later on, on the model with the vertical scale exaggerated. On the geometrical similar model the slope in the bed was first increased to five times the original and then two and a half times. On the model with the vertical scale exaggerated, tilt giving slope two and a half times the original was examined. It was shown from these investigations that it was better to construct a large scale vertically exaggerated model than to use tilt. In models at Malikpur no additional tilt is now used.

The Discharge Scale. According to Froude the model discharge can be calculated from the formula.

$$q_p = q_m \, l \, d^{\frac{3}{2}}$$

where l is the horizontal scale and d is the vertical scale and q_p and q_m are prototype and model discharges respectively. The discharge scale is determined experimentally as below :—

The method of determining the discharge scale ratio consists in letting water into the model so as to reproduce certain prototype gauges, the river discharges for which are known. The actual discharge of the prototype divided by the model discharge which reproduces the gauges of the prototype gives the discharge scale.

The discharge ratio can also be derived from Manning's formula. If the cross-sections are flat enough to permit substitution of the depth for hydraulic mean radius, the discharge could be calculated by the formula :—

$$q = \frac{l^{\frac{1}{2}} \, d^{\frac{13}{6}}}{n} \text{ approximately.}$$

If the model is not built according to the principles of simple distortion but an additional tilt is given to the model to facilitate bed load movement, the following formula can be used for the calculation of the discharge :—

$$\frac{l \, d^{\frac{5}{3}} \, s^{\frac{1}{2}}}{n}$$

Value of n according to Vogal is nearly unity for models built to horizontal scales between 1/1,000 to 1/500. It may be mentioned that these formulae give only an approximate estimate of the discharge required on the model. It is essential to determine experimentally the exact discharge scale ratios by the method of reproduction of gauges as mentioned above.

Velocity Scale Ratio. The velocity produced in a freely falling body under the influence of gravity is given by the relationship.

$$V = \sqrt{2\,g\,H}$$

$$\text{and } v = \sqrt{2\,g\,h}$$

$$\frac{v}{V} = \frac{\sqrt{2\,g\,h}}{\sqrt{2\,g\,H}}$$ Since H/h is d or vertical scale.

$$\frac{v}{V} = \frac{1}{\sqrt{d}} \quad \text{or } V = \sqrt{d}\,v$$

or expressed in words the velocity scale is equal to the square root of the vertical scale.

V = Velocity on the Prototype.

v = Velocity on the Model.

The velocity can also be calculated from Manning's formula taking into consideration the ratio between the roughness of the bed on the model and the prototype. It is shown from model tests that the bed on the model moulded with the actual river sand is rougher than that on the prototype.

The Time Scale. The time scale ratio is experimentally determined. The procedure adopted is to mould the model according to a given survey of the prototype. Equivalent discharges are then run on the model for a certain period at the end of which the bed is surveyed and is compared with the corresponding survey on the prototype. The time scale ratio which closely reproduces the silting and scouring on the model is adopted.

The Silt Scale. If the time scale is found to be too large, the grade of sand used on the bed is altered. The material which gives a convenient time scale is selected.

The Silt Charge. In order to maintain the bed equilibrium a certain quantity of the material of a selected grade is added at the upstream end of the model during its operation. For models on sand bed, the same grade of sand as used on the bed is added. For models with shingle and boulder beds, a mixture of shingle and sand is added during the run. The amount and size of shingle added is varied according to the discharge run, larger size material being added in high discharges. The amount of material to be added is experimentally determined. The procedure adopted is as follows :—

The model is first run with varying discharges without adding any sand. The material removed from the bed of the model during the run is collected downstream of the model and measured. In the next test the same quantity as that collected downstream in the first test is added during the course of the run and the material collected downstream of the model is again measured.

In this way a series of runs is made until the quantity of material collected downstream is the same as that added at the upstream end of the model. The quantity of material which maintains the bed equilibrium is the correct charge to be used on the model.

6. Reduction of the River Survey Plans and Sections. The survey plans and the sections received from the local officers are reduced according to the scales fixed.

7. Construction of the model. The procedure adopted for the construction of the model is as follows :—

(*a*) *Laying-out the model.* A convenient reference line is first marked on the tray in which the model is to be constructed. The section lines are then laid, with respect to the reference line

(*b*) *Fixation of the Datum.* A suitable datum is fixed taking into consideration the following points :

1. The earthwork required to construct the model should be minimum.
2. The required head to feed the model from the supply channel should be available.
3. The required fall for escaping the water after use on the model should also be available.

(*c*) *Laying-out the Sections.* The levels for various sections are given and iron pegs $\frac{1}{4}''$ diameter are erected at each point to the required height. The use of pegs has proved to be of great help in the initial moulding and in the subsequent remouldings of the model. The pegs do not interfere with the flow.

In order to facilitate the work of giving levels two or three masonry pillars are constructed at suitable places in the tray to serve as stands for the levelling instruments ; the advantages being that the level is not disturbed and the calculations for the reduced levels are made only once.

The earth for a depth of one foot below the level of the sections is taken out and replaced with sand or shingle as the case may be.

(*d*) *Moulding the bed.* The bed between the different sections is moulded according to the plane table survey. The extreme upstream and downstream sections are made rigid. Rigid structures, such as weirs, regulator and spurs, are made in masonry.

(*e*) *Proving the model.* Before carrying out tests the model is first proved from the previous year's surveys. The model is moulded to a certain year's survey and run for the discharges corresponding to those experienced on the prototype the year just after the survey. The survey on the model taken after the run is compared to the prototype survey of the corresponding period. In addition, the river gauges, velocities at various points, the silting and scouring and the directions of flow are compared. If the model reproduces changes occurring on the prototype it is regarded as working satisfactorily and suitable for carrying out tests.

B. Methods employed for the investigations of Rigid Bed River Models. For the investigation of certain problems, models with rigid beds have been examined. The bed is moulded according to given sections in cement.

These models are only helpful in determining the river gauges. Before carrying out experiments with the rigid model it is essential to adjust the bed of the model for known conditions of flow.

C. Methods employed for the investigation of models of canal works. The methods for the investigation of models of canal works are much simpler than those used in the river models.

1. *The Data.* The data required in connection with these investigations are as follows:—

(*a*) Plans and sections of the rigid structures.

(*b*) Plans and sections of the channels a short distance up and downstream of the works.

(*c*) Full supply and low supply discharges with corresponding upstream and downstream water levels.

(*d*) Position of gauges.

(*e*) Samples of bed and bank.

2. Fixation of scales. Fer models of falls, weirs, regulators, etc., in which the standing wave is formed, the horizontal and vertical scales adopted are the same. The scale is fixed keeping in view the following points :—

(*i*) The scale selected should be such that the velocity of flow on the model can effect scour in the bed and erosion at the sides.

(*ii*) The required discharge on the model can be obtained from the supply channel.

3. The selection of the bed material. The bed material to be used on the geometrically similar model has to be determined experimentally. Different grades of material are examined and the one which gives the depth of scour on the model corresponding to that developed on the prototype is selected. Different grades do not produce great differences in the depth of scour. A detailed investigation was made in this connection and the results are given separately 1, 2.

4. Time scale or period of run. For geometrically similar models no time scale can be fixed. The model, however, is run for different periods to determine the time which gives the equilibrium conditions of the bed. The equilibrium conditions are those conditions in which the depth of scour obtained is maximum. It may, however, be mentioned in this conection that the depth of scour is not proportional to the period of run. In the first one or two hours the action on the bed is very great

1. Studies in bed scour below masonry works. Part I. The influence of grade of bed material.

2. Part II. The influence of period of run, by Harbans Lal Uppal, M.Sc., Ph.D. (Type-written).

and then it slows down. The relationship between the depth of scour and the time of run is of exponential character.

5. **The construction of the model.** The method of construction of the model is similar to that adopted for the construction of rigid structures in river models.

VI. AN ACCOUNT OF SOME OF THE INVESTIGATIONS MADE AND VERIFICATION OF MODEL RESULTS FROM OBSERVATIONS ON THE PROTOTYPE.

One example only of each type of investigation carried out is given below :—

A. River Diversion and River Training

1. *River Diversion.* The experiments carried out on a model of the River Sutlej 14 miles above Suleimanki Headworks in order to determine suitable methods of river diversion are described briefly.

The problem. The River Sutlej upstream of the Suleimanki Headworks divides into three channels.

(*i*) The main or central channel.

(*ii*) The right channel or the Lalu Gudar Creek, which takes off the main stream at mile 25 above the weir.

(*iii*) The Hasta Creek or the left channel, which takes off the central channel at mile 11 upstream of Suleimanki Weir.

The central channel in the past took a greater portion of the discharge in the river. During the recent years, however, the Hasta Creek developed considerably and carried as much as 57 per cent of the total river discharge. Due to the development of the Hasta Creek, the left marginal bund was attacked at several places. In the year 1940, the conditions became worse and the left marginal bund was heavily attacked. It was feared, that if no action was taken the Hasta Creek might develop further and the river might outflank the weir. It was, therefore, decided to divert the river and close the Hasta Creek. In order to close the Hasta Creek it was first decided to construct an armoured spur at about R. D. 55,000 of the left marginal bund.

The Model. A model representing 14 miles of the river upstream and a short length downstream of the Suleimanki Weir was constructed. The whole of the river area between the right and the left marginal bunds was represented.

The Scales adopted The following scales were adopted :—

Horizontal :	Model to Prototype	...	1 to 150.
Vertical :	,, ,, ,,	...	1 to 25.
Exaggeration :	...	...	6.

No additional tilt was given.

It was shown on the model that in the place of an armoured spur an earthen bund with pilchhi protection on the upstream side at

R. D. 52,000 would divert the river satisfactorily. The model with the bund in position is shown in Fig. 5.

The following tests were carried out with the earthen bund :—

(*a*) The action on the shank and nose of the bund with discharges representing the monsoon of 1941.

(*b*) Gauges at the nose of the bund.

(*c*) The effect of the river diversion on the central and the right channel especially at the point where they flowed close to each other. The main points required to be determined were :—

(*i*) Will the two channels unite ?

(*ii*) If they joined, what would be the discharge at which the junction would occur ?

(*iii*) Will the right channel become the main channel ?

(*d*) Action of the flood discharges on the shank of the Dharanga Spur.

The model was examined for river discharges up to 200,000 cusecs only. The model experiments showed that :—

(*i*) No attack would occur either on the shank or at the nose of the bund with river discharges up to 2 00,000 cusecs. The nose would remain unaffected.

(*ii*) The central and the right channel would join and the junction would take place with a discharge of about 60,000 cusecs.

(*iii*) The right channel would not develop further. It would continue to draw its proportionate discharge as it has been drawing in the previous year. It was also shown that an attack might occur on the shank of the Dharanga Spur with a discharge of 200,000 cusecs.

The bund according to the design and position obtained on the model was constructed in the same year. Observations were made by the local officers in the monsoon of 1941. The results obtained on the prototype were compared with the model predictions and are given below :—

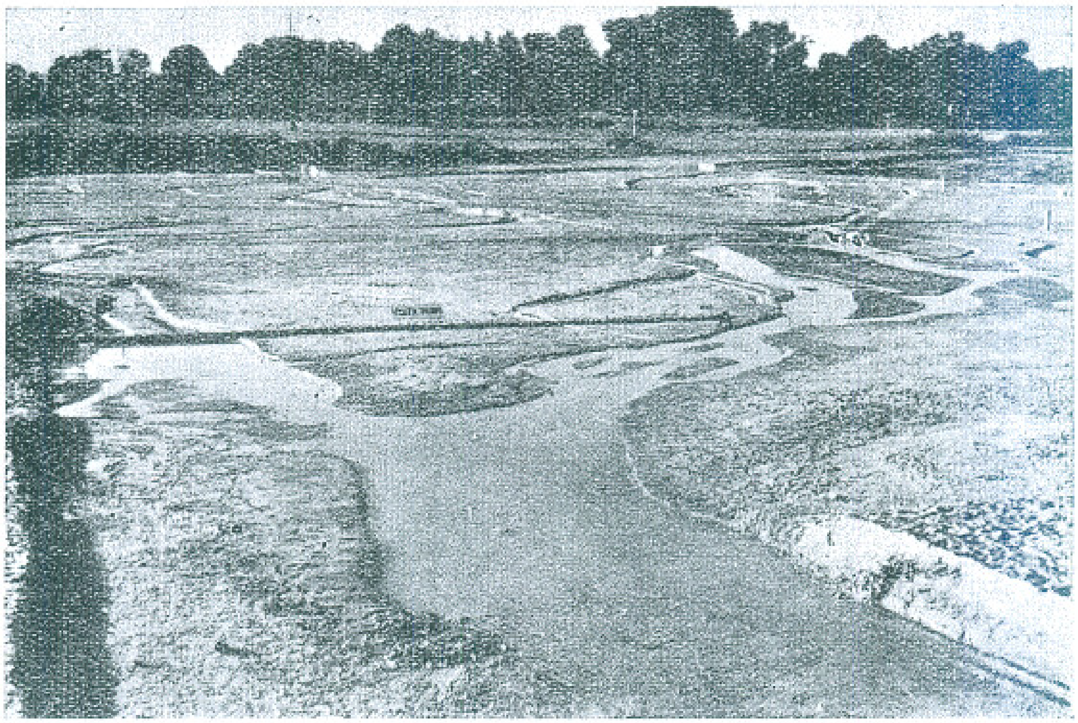
Verification of the model results from observations on the prototype.

River Gauges :

Gauges at Hasta Bund above Suleimanki Headworks. The prototype gauges at the nose of the Hasta Bund on the River Sutlej above Suleimanki Headworks recorded in the monsoon of 1941 are compared below with the model predictions for the same period :—

RIVER SUTLEJ UPSTREAM OF SULEIMANKI HEADWORKS.

Fig. 5.



A model of the River Sutlej 14 miles above Suleimanki Headworks. This model represents the Lalu Gudar Creek and the Central channel. The Hasta channel is closed by the earthen bund marked AA.

Scales adopted :—

Horizontal — Model to prototype	...	1 to 150.
Vertical — Model to prototype	...	1 to 25.
Exaggeration	...	6.
Diameter of sand used on the bed	...	0·3—0·5 mm.
Area occupied by the model	...	500′×400′.

Discharge on the model corresponding to the maximum flood on the prototype ... ... = 20 cusecs.

Serial No.	PROTOTYPE OBSERVATIONS RECORDED IN THE MONSOON OF 1941		MODEL PREDICTIONS FOR MONSOON 1941.	
	Discharge in cusecs.	Gauge R. L.	Gauge R. L.	Discharge in cusecs.
1	98,708	579·6	579·5	100,000
2	73,445	578·8	579·0	75,000
3	69,900	578·9	578·8	60,000
4	31,550	577·2	577·3	30,000
5	21,368	575·3	575·5	20,000
6	12,345	575·4	575·6	12,500

From an examination of the above table it will be seen that the agreement between the model predictions and the prototype results for the river gauges for the corresponding discharges is good.

The correlation between the model and the prototype gauges was calculated statistically. *A value of* 0·998 *was found which is a fairly high correlation co-efficient.*

Verification of the behaviour of the Central and the Right channel.

It was predicted on the model that the junction of the central and the right channels would take place in 1941 in a discharge of about 60,000 cusecs and after the junction each channel would draw its own discharge. Observations on the prototype showed that the junction took place in a discharge of 70,000 cusecs and each channel took its own discharge.

The observations obtained after the junction took place are given below :—

Serial No.	Right Channel above junction.	Right Channel below junction.	Central Channel above junction.	Central Channel below junction.
1	17%	17%	83%	83%
2	15%	15%	85%	85%
3	13%	13%	87%	87%

From a perusal of the above it will be seen that the behaviour of the prototype was very similar to that of the model. The model predictions were only for the conditions up to the end of year 1941. Observations on the prototype were continued in the subsequent years. In the year 1942, however, unprecedented high floods of very long durations occurred on the prototype.

Up to a discharge of 300,000 cusecs the Hasta bund was very efficient. However in a discharge of 325,000 cusecs some damage occurred to the nose of the bund. The model was re-examined to determine the conditions of the bund at the end of 1943. It was shown from the model experiments that a portion of the bund may be washed away if the year 1943 was a high flood year like that of 1942.

2. **River Training.**

River training above and below Canal Headworks—an investigation of methods to maintain a channel centrally above the weir.

The approach of rivers to the weirs is often oblique. This oblique approach results in the formation of large islands at undesirable places in the weir pockets. The islands formed are sometimes so large that they obstruct flow taking place into the canals.

Several methods to straighten the approaches have been investigated. Some of these are :—

1. Construction of Armoured Spurs projecting from the river banks opposite to each other.

Experiments have been carried out with projected spurs in order to tighten the river above the weir. Heavy action, however, occurs at the spurs with this arrangement.

2. Construction of Artificial pitched Islands in the Rivers. The effect of artificial islands constructed in the river-bed has been examined. The programme of work in this connection has been to construct a series of islands. The method adopted was to construct an island first near the existing tortuous path of the river and then by stages shift it towards the central line of the weir.

The conditions of the channel after run in the presence of one island constructed upstream of the guide banks of the Suleimanki Weir is illustrated in Fig. 6, 6-A and 6-B. It will be seen from an examination of this figure that the island attracted the river towards it.

In continuation, the effect of the construction of a series of islands one above the other was determined. The islands were shifted towards the central line to the weir in stages as already stated. Three islands examined were placed as given below :—

First at 7,200 feet, second at 13.000 feet and third at 19,000 feet above weir.

As an alternative measure three islands were constructed along the centre line to the river. They were joined to the main river by a leading cut. This is shown in Fig. 7.

The method appears to be promising. Further investigations are being carried out.

Meandering of Rivers. Various factors responsible for causing meandering are being investigated.

The first series of experiments was carried out with a fixed discharge but varying charge. Different quantities of material were investigated to determine the charge at which meandering commenced.

B. Bank Protection.

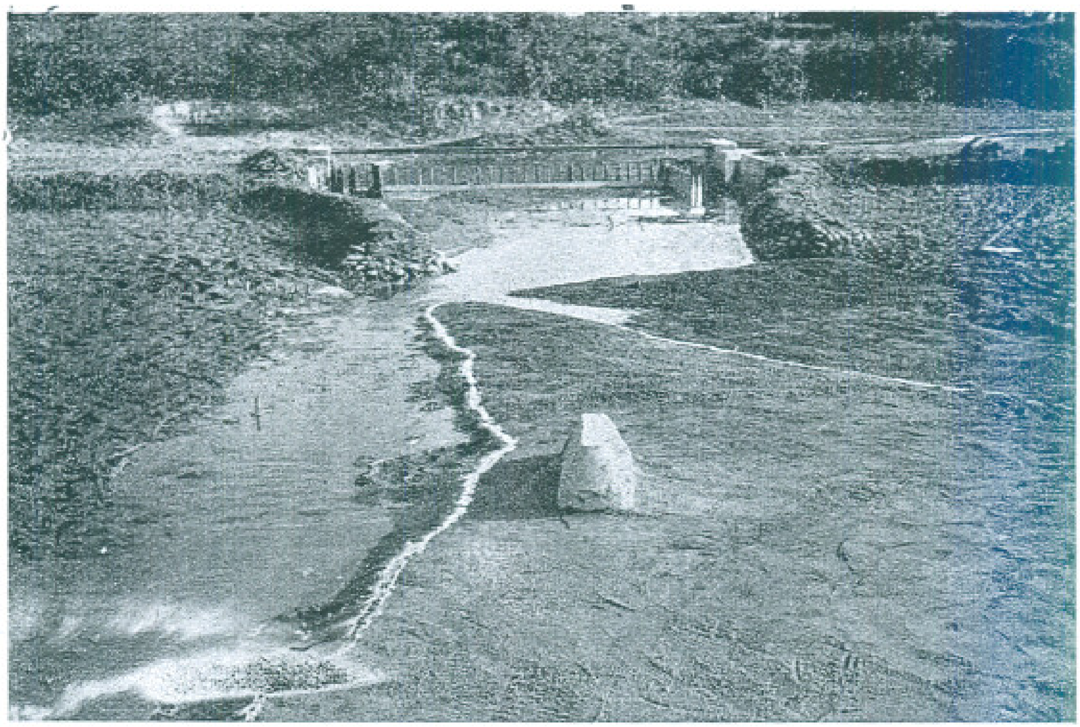
Bank protection has been studied in detail on the Beas River model.

The River Beas had been eroding its left bank between the villages Dhanua and Kullah. A number of retired embankments were constructed but they were washed away. In 1939 the river eroded its left bank very heavily and threatened to wash away the last retired bund known as the 2nd Kalewal bund. This is shown in Fig. 8. The seriousness of the situation was due to the fact that there was no room for further retirement on account of the proximity of a large drainage known as the Western Bein. The water surface level in the Bein was 10 feet lower than the highest flood level of the river. Any breach in the 2nd Kalewal

RIVER TRAINING BY MEANS OF ARTIFICIAL PITCHED ISLANDS.

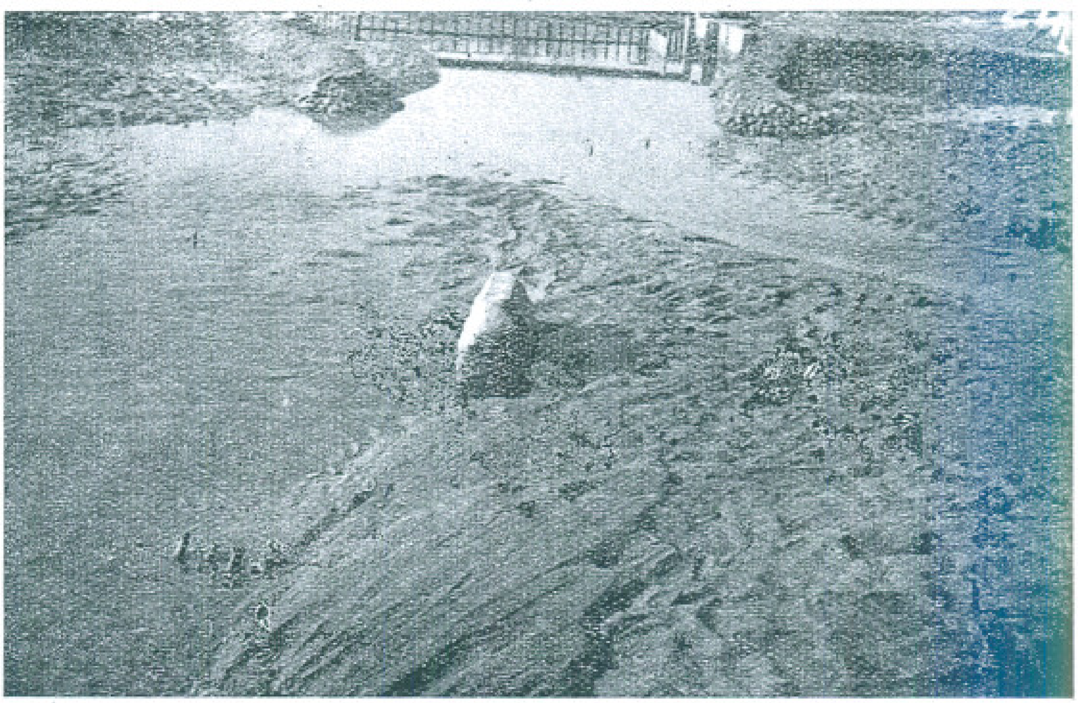
An investigation of the effect of constructing an artificial pitched island in the river bed in order to maintain a channel central, to the weir.

Fig. 6.



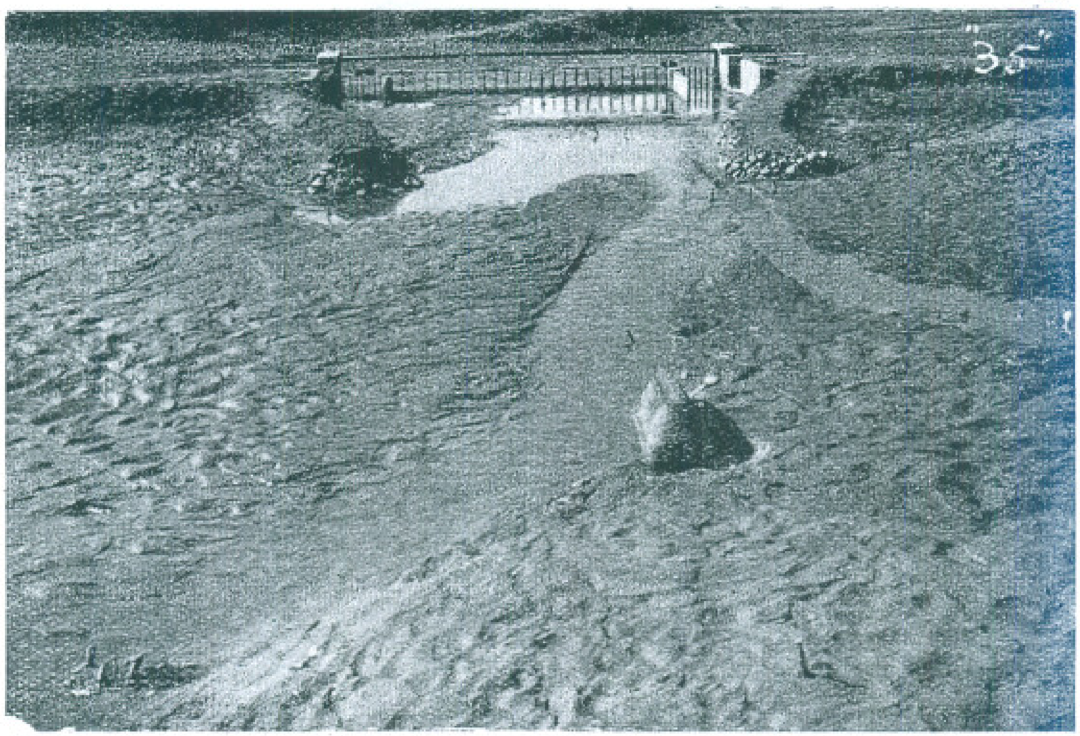
An island 75 ft. × 300 ft., constructed at 7,200 ft. upstream of the Suleimanki weir on the bela close to the river edge.

Fig. 6-A.



Model run for one season in the presence of the island. This photograph shows the river conditions in the dry. It will be seen that the main channel is now situated along the left edge of the artificial island. A scour occurs at the nose. Erosion also takes place upstream of the nose of the island.

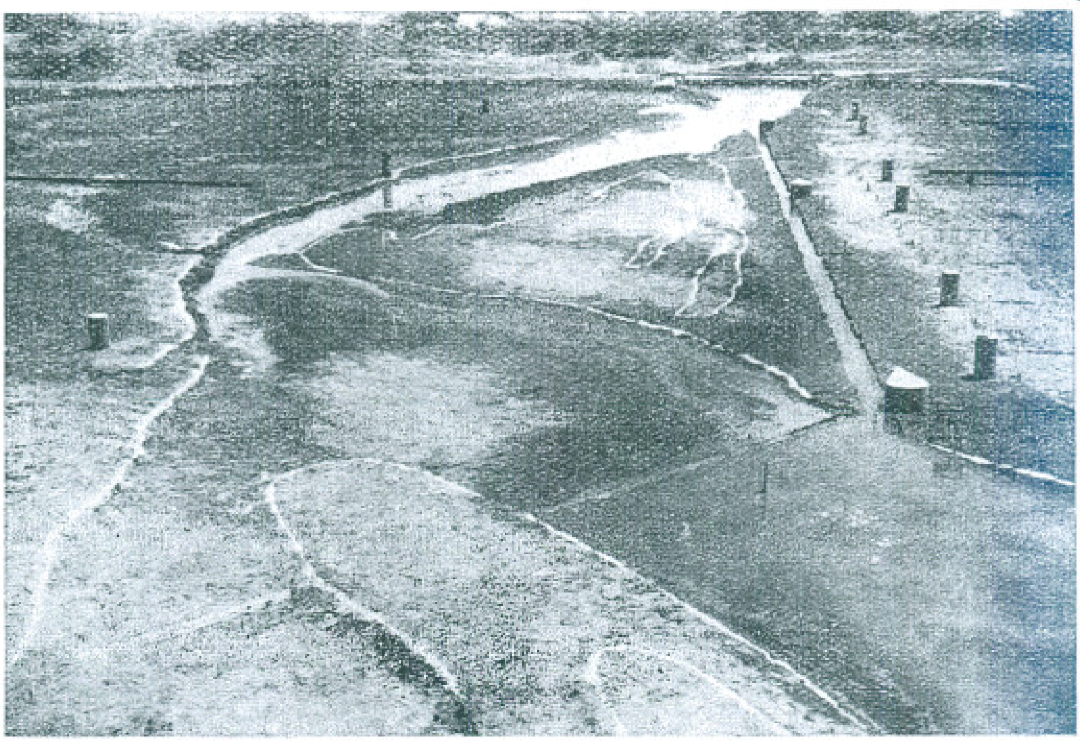
Fig. 6-B.



The island constructed at 7,200 ft. along the central line to the weir. This photograph illustrates the conditions after running the model for one season in the presence of the island in the new position. It will be seen that the channel is now situated central to the weir. It is rather on the right.

RIVER TRAINING BY MEANS OF ARTIFICIAL ISLANDS.

Fig. 7.



Model running with a discharge of 1,600 cusecs.
This photograph shows the river diverted to the pitched island by a leading cut and a bund. Three islands are constructed along the central line to the weir.

FIG. 8
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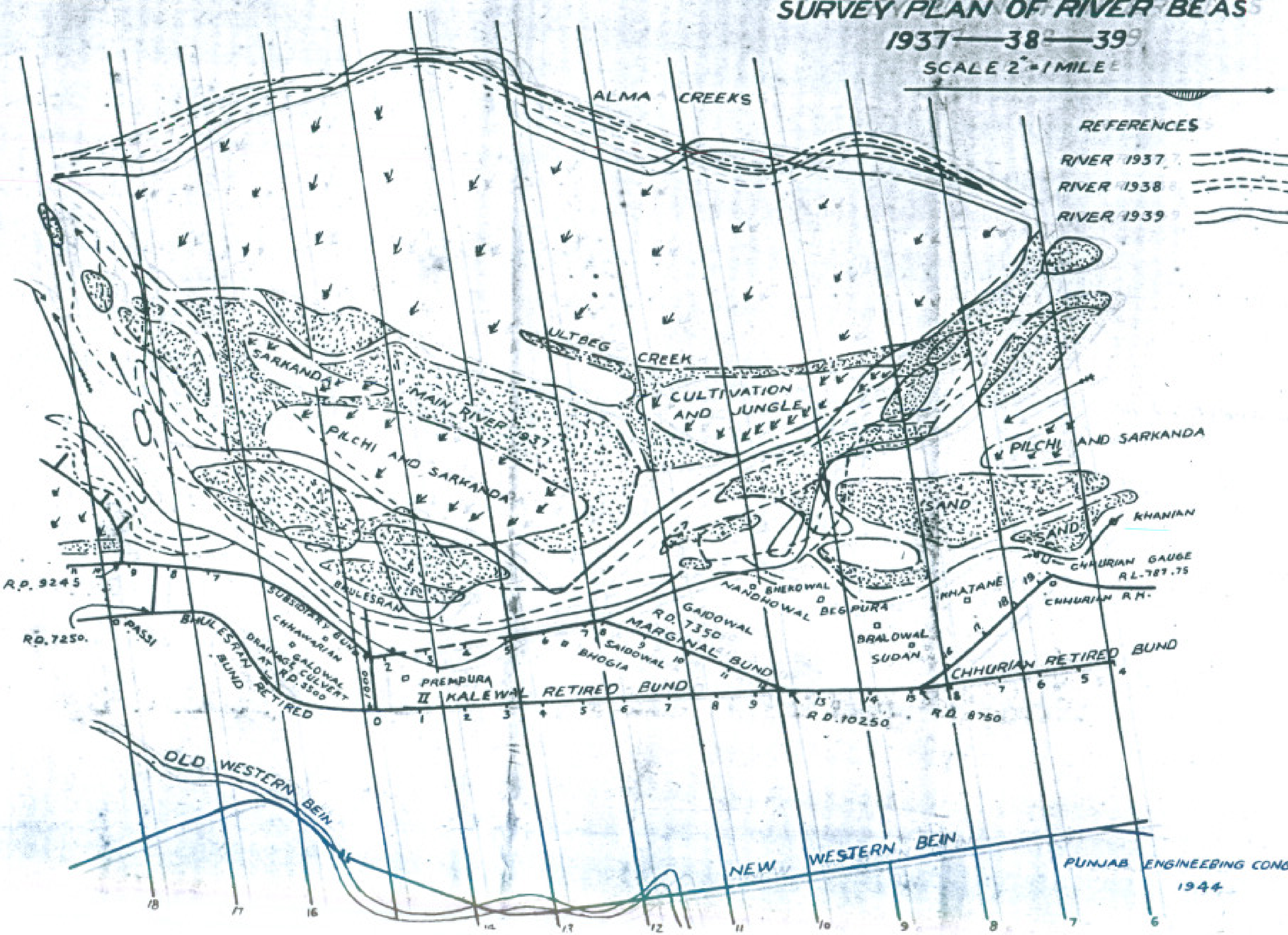
SURVEY PLAN OF RIVER BEAS 1937—38—39



PUNJAB ENGINEERING CONGRESS
1944

Retired Bund was likely to divert the major portion of the discharge of the river into the Western Bein. If the river breached the bund and joined the Bein it would cause disaster to a large part of the Kapurthala State and considerable damage to the main line of the North-Western Railways.

In a joint meeting of the Chief Engineer Irrigation Works, Punjab, representatives of the Kapurthala State and the North-Western Railways it was decided to investigate a model of the River Beas of the reach where erosion of the left bank was taking place in order to study suitable methods of protecting the bank.

A model of the River Beas for a length of 7 miles between the villages Dhanua and Kullah, was constructed. The Alma Creek was also represented on the model. The retired bunds which existed at the end of 1938 were constructed and the position of the Western Bein and important villages situated on the left bank was marked on the model. A view of the completed model is given in Fig. 9. The following scales were adopted :—

Horizontal	:	Model to Prototype.	1 to 100.
Vertical	:	,, ,, ,,	1 to 20.
Exaggeration	:	...	5 (Besides the simple exaggeration no additional tilt was given).

Time Scale : 12 hours on the model equal to 1 month on the prototype.

After proving the model the following tests were carried out :—

(*i*) Determining the most suitable position, dimensions and shape of spurs for protecting the left bank of the river ;

(*ii*) Determining the probable river conditions at the end of 1940 with the spurs in position ; *and*

(*iii*) Determining the probable river conditions at the end of 1940 if the spurs were not constructed.

It was shown from these experiments that it was necessary to construct at least three spurs for the protection of the left bank near the Western Bein. The most suitable shape of the spurs was found to be 'T' head, the length of the head of each spur being 350 feet ; 250 feet upstream and 100 feet downstream of the pivot point. To determine the probable river conditions at the end of 1940 with the spurs in position, the model after moulding the bed to November 1939 Survey, was run for a period equivalent to one year. It was shown that even in the presence of the spurs, erosion of the left bank would occur to a certain extent and a few villages would be washed away. The tests without the spurs showed that the damage to the left bank would be much greater.

The spurs were built at site in the year 1940 according to the position and design obtained on the model. Observations were made in the monsoon of 1940 and were compared with the model results given in the forecast report for the year 1940. The forecast report was submitted in February 1940.

Verification of the results. The verification of the results is made for the following points :—

(*i*) The River Gauges.

(*ii*) The depth of scour at the spurs.

(*iii*) The directions of flow, channel and bela formation.

(*iv*) The extent of erosion of the left bank.

Before discussing the results it is necessary to examine the discharges, which occurred on the prototype in the monsoon of 1940 in order to find out how far these discharges compared with those run on the model to represent the discharge conditions of the year 1940. This is given below :—

Discharges assumed on the model to represent 1940 conditions.	Discharges which were experienced on the prototype in the monsoon of 1940.
Four high floods, the highest being over two lacs cusecs and two medium floods were run. In addition, discharges of 33,000 and 67,000 cusecs were also run for ten days each to represent low floods.	There occurred four high floods of 154,000, 152,000, 124,000 and 102,311 cusecs, three medium floods and about ten low floods as recoded by the gauge at Dera Gopipur.

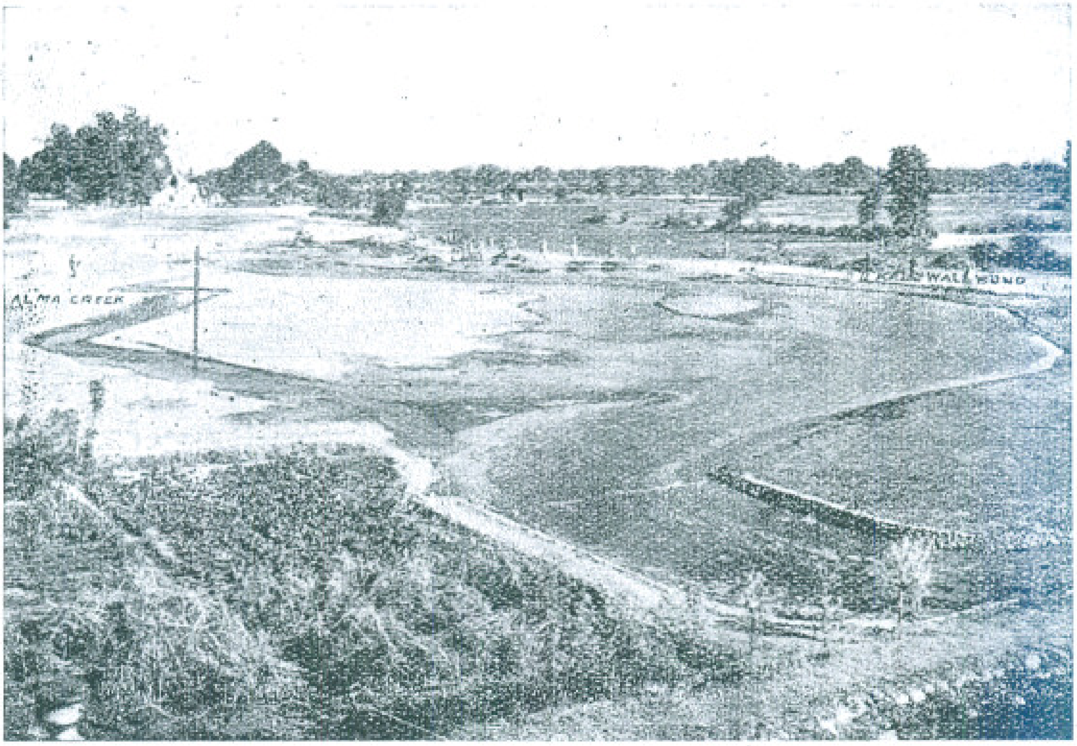
The discharge conditions experienced on the prototype may, therefore, be considered roughly similar to those examined on the model.

(*i*) The River Gauges for the model and the prototype for the corresponding discharges are given below :—

Prototype observations recorded in the monsoon of 1940.		Model predictions or monsoon 1940.	
Discharge in cusecs.	Gauge.	Gauge.	Discharge in cusecs.
	Spur No. 1.		
66,287	R. L. 783·65	R. L. 783·4	67,000
91,000	R. L. 783·9	R. L. 783·6	91,000
124,000	R. L. 785·30	R. L. 784·6	127,000
	Spur No. 2.		
66,287	R. L. 781·95	R. L. 782·3	67,000
86,000	R. L. 782·40	R. L. 783·0	91,000
124,000	R. L. 783·0	R. L. 784·0	127,000
	Spur No. 3.		
66,287	R. L. 780·25	R. L. 780·7	67,000
86,000	R. L. 780·95	R. L. 781·2	91,000
124,000	R. L. 782·10	R. L. 782·0	127,000

RIVER BEAS NEAR THE WESTERN BEIN.

Fig. 9.



This photograph shows a view of the model of the River Beas for a length of 7 miles near the Western Bein. The model represents the main river, all the retired embankments as existed in 1939 and Alma Creek. Scales adopted :—

Horizontal	... ...	1 to 100
Vertical	... ...	1 to 20
Exaggertion.	... .	5

Area occupied by the model .. ... = 400′×200′.

Discharge on the model corresponding to the maximum discharge on this prototype ... ... 48 cusecs.

It will be seen from the above table that, allowing for the differences in the discharges tested on the model and the actual discharges recorded on the prototype, a close agreement exists between the model and prototype gauges. The correlation between the behaviour of the model and the prototype gauges worked out to be 0·999.

(*ii*). *The depth of scour at the spurs.* The depth of scour obtained in each case on the model and the corresponding scour on the prototype is given below :—

Prototype observations recorded in the monsoon of 1940.	Model predictions for monsoon of 1940.
Scour R. L. at the pivot point.	River-bed at the pivot point.
Spur No. 1.	
R. L. 760·0 after 124,000 cusecs discharge.	... R. L. 760·8.
R. L. 760·0 after 158,000 cusecs discharge.	
Spur No. 2.	
R. L. 760·6 after 124,000 cusecs discharge	R. L. 764·0
Spur No. 3.	
R. L. 755·9 after 1,24,000 cusecs discharge	R. L. 756·0
R. L. 754·8 (Not at pivot point) after 158,000 cusecs discharge.	

It will be seen from the above table that the agreement between the model and the prototype values for Spurs No. 1 and 3 is good. In the case of Spur No. 2 there is a difference which has not been accounted for but may be due to local difference in erodibility of the soil.

(*iii*). *The directions of flow, channel and bela formation.* The current directions, channel, and bela formation as observed on the prototype are compared with those predicted on the model in the table given below :—

Model predictions for 1940.	Prototype observations recorded in 1940.
1. The model showed that at Spur 1 smooth flow would take place at the nose and along the head of the spur and that the approach of the river at Spur 1 would alter considerably. A large bela would form in front of Spur 1	1. The prototype records showed that smooth flow took place at the nose and along the apron of Spur 1. The river approach at the end of year 1940 is shown in Fig. 10-A. It will be seen that a large

and the river on the right would cross over to the left, downstream of Spur 1. This is shown in Fig.10.

bela formed in front of Spur 1 and that the river from the right crossed over to the left, downstream of Spur 1. Conditions obtained in Fig. 10 and 10-A are exactly similar.

2. It was predicted that downstream of Section 12, the main current, which was originally close to the left bank, would move towards the centre of the river with the result that an island would be formed between Sections No. 12 and 13·5.

2. Detailed survey of the river between Sections 12 and 13·5 showed that

(*a*) At Section 12 the main current was situated close to the left bank.

(*b*) At Section 12·5 the main current moved away from the left bank.

(*c*) At Section 13 the main current moved away from the left bank towards the centre of the river.

(*d*) The main current returned to the left bank at Section 13·5 and an island formed between the deep channel and the left bank.

Further evidence of the above was afforded by the current directions given in Fig. 10 B. It will be seen from this photograph that at Section 12·5 the main current which originally existed close to the left bank got a kick and made a large loop towards the centre. It then returned to the left bank at Section 13·5. The bela which formed, between Sections 12 and 13·5 is clearly shown in this photograph.

3. The model indicated that downstream of Spur No. 2 the main current would hit the left bank at Section 15.

3. Downstream of Spur No. 2 the main current hit the left bank below village Prempura at Section 15. Prototype records regarding the main attack on the left bank showed that it was directed against the village Chhavrian which existed at Section 15.

RIVER BEAS NEAR THE WESTERN BEIN.

Fig. 10.

This photograph shows the action at Spur No. 1 on the model.

The large bela which has formed in front of the spur and the crossing of the river from the right to the left downstream of the spur is clearly shown in the photograph.

RIVER BEAS NEAR THE WESTERN BEIN.

SPUR No. 1.

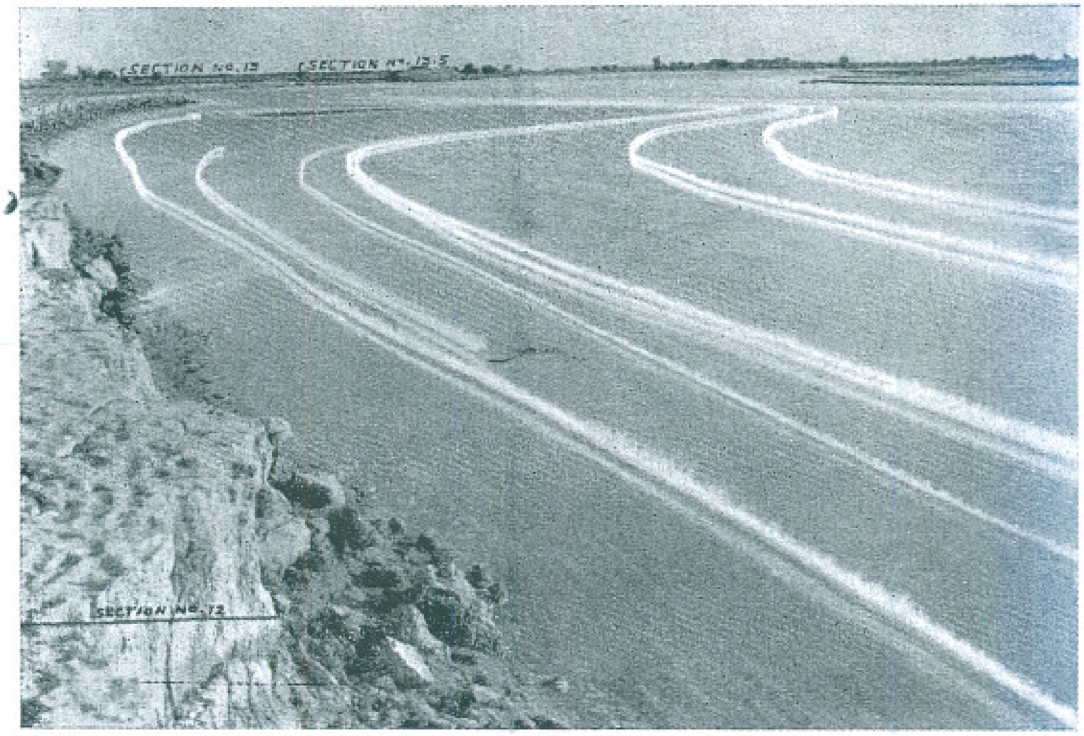
Fig. 10A

This photograph illustrates the shifting of the main current from the left to the right on the prototype. The main river which at this point was on the left before the construction of the spur is now situated on the right. It takes a course to the left downstream of Spur No. 1. Upstream of the spur and close to the left bank bela formation takes place.

RIVER BEAS NEAR THE WESTERN BEIN.

Left bank of the river between Section 12 and 14.

Fig. 10-B.



This photograph shows the directions of flow between Sections 12 and 13·5 on the prototype. It will be seen that at Section 12 the river is concentrated along the left bank. Downstream of Section 12 the river is deflected towards the centre as shown by the floats but it again comes back to the left bank at Section 13·5 ; thus forming an island between Sections 12 and 13·5.

4. The model showed that heavy action would take place at the nose of Spur 3.	4. The action at the nose of Spur 3 was "very severe". It will be seen from Fig. 11 that all the floats, even those from the right bank of the river, hit the spur at the nose.
5. It was predicted from the model that at Section 17 the deep channel of the river would move towards the centre.	5. At Section 17 the deep channel of the river which originally existed close to the left bank was situated at the end of 1940 at a distance of 300 feet from it.

(*iv*). *The extent of erosion of the left bank.* A detailed survey of the left bank of the river was made in October 1940. A comparison of the erosion line as determined on the model for 1940 is made with prototype survey. This is given below :—

Model Predictions for 1940.	Prototype observations recorded after monsoon 1940.
The model predicted that :	It was observed on the prototype that :
1. The river would erode the left bank between Spur 1 and 2 in two deep curves.	1. The river eroded the left bank between Spurs 1 and 2 in two deep curves.
The first curve would be between Spur 1 and the village Saidowal and the second one would be downstream of Section 12.	The positions of the curves were identical with those predicted on the model.
2. Downstream of Spur 1 the left bank would be eroded for a length of 3,500 feet but the erosion between Sections 11 and 12 would be rather heavy.	2. Downstream of Spur 1 the left bank of the river was eroded mostly up to 4,000 feet. The erosion between Sections 11 and 12 was heavy.
3. Heavy erosion would occur at Section 15 and downstream, *i.e.*, at Chhavrian.	3. Heavy erosion took place at Chhavrian and the village was washed away.
4. Villages Prempura, Saidowal and Chhavrian would be washed away due to the erosion of the bank. A warning was issued to the inhabitants of these villages by the Deputy Commissioner, Hoshiarpur District on the basis of the model tests.	4. All these villages were attacked. Chhavrian was completely washed away. A great part of village Prempura and Saidowal, was also washed away.

The erosion values on the model and on the prototype at similar points are given below :—

	Model Predictions.	Prototype Observations recorded.
Maximum above Saidowal ...	400′	460′
Upstream of Bhogia ...	460′	350′
Maximum between Khepran and Spur No. 2.	500′	500′
Opposite Khepran ...	460′	500′
Opposite Prempura ...	400′	436′
Maximum near Galowal ...	760′	840′

General Conclusions. It will be seen that the agreement is close. From the above study it was shown that—

(*i*) The armoured spurs constructed on the River Beas behaved according to the model predictions.

(*ii*) The prototype and the model gauges corresponding to different discharges agreed closely.

(*iii*) The depth of scour on the model and on the prototype at the spurs agreed well except at Spur 2.

(*iv*) The current directions on the model and on the prototype at corresponding points agreed closely.

(*v*) The bela formation between Sections 12 and 13·5 agreed well with that predicted on the model.

(*vi*) The deep channels on the prototype occurred at places predicted on the model.

(*vii*) The extent of erosion on the left bank at almost all the points agreed fairly well with that predicted on the model. The point of maximum erosion on the model and on the prototype was similar.

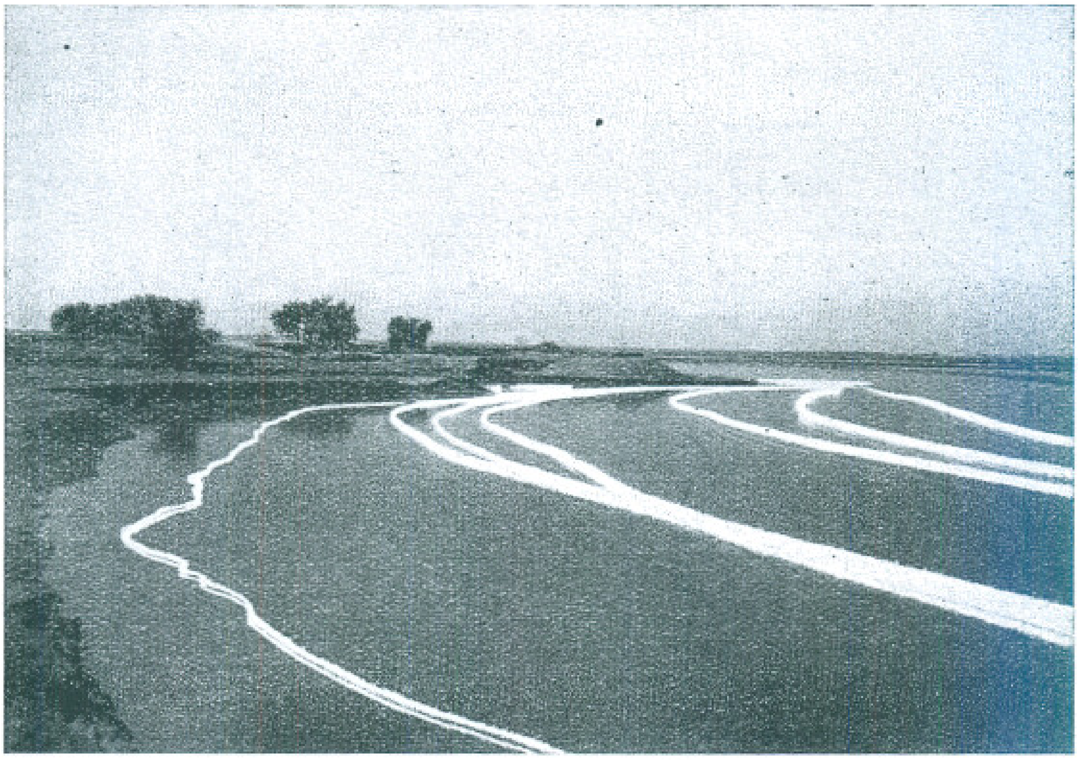
In the year 1942 during the monsoon certain damage occurred to the armoured spurs on the River Beas. This was due to the unprecedented high floods of very long duration. In 1942 the River Beas at the armoured spurs was in high floods over 100,000 cusecs for more than thirty days against three or four days in a normal year. The highest flood recorded at Dera Gopipur in 1942 was 384,000 cusecs against 284,000 cusecs ever recorded. The dominant river discharge at the spurs in 1942 was twice as much as the discharge in a normal year.

Further Model Investigations. In order to investigate the most suitable methods of protection of the left bank, further model experiments were carried out. For the purposes of this investigation a new model (since the old model had been dismantled) was constructed. The scales adopted were the same as those used for the first model. All the items represented on the first model were reproduced. This model, however, represented a much longer length of the river.

RIVER BEAS NEAR THE WESTERN BEIN.

SPUR No. 3.

Fig. 11.



This photograph illustrates the heavy concentration of flow at the upstream nose of the spur on the prototype. It will be seen that the floats from the extreme right edge also strike at the nose of the spur resulting in a heavy action at this point. Just upstream of the spur there is an embayment and swirl formation as shown by the circles in the photograph.

The following tests were made :—

1. Determining the probable river conditions of Beas at Armoured Spurs at the end of 1943, if no work was done on the spurs.
2. Determining the probable river conditions of Beas at Armoured Spurs at the end of 1943, if a new spur, proposed by Mr. Inglis, was constructed on the right bank of the river downstream of Spur No. 3.
3. Determining the probable river conditions of Beas at Armoured Spurs at the end of 1943, if the old spurs were maintained.

The discharges used. The discharges used for running the model were those experienced in the year 1942.

The results obtained. The results obtained are given below in brief :—

1. If no work is done on the spurs heavy bank erosion takes place especially between Spurs No. 2 and 3. The left river edge between the spurs is shown in Fig. 12.
2. If the spur proposed by Mr. Inglis is constructed the erosion of the left bank is approximately the same as that obtained without the new spur. There is a slightly greater erosion with the new spur, at the site of Spur No. 3.
3. If the existing spurs are maintained by constructing suitable shanks, the erosion of the left bank is much less especially at the site of Spur No. 2 than that obtained without maintaining the spurs. Between Spurs No. 1 and 2 there is practically no erosion. The left river edge with the spurs maintained is only slightly eroded between Spurs 2 and 3.

Construction at Site. The new spur on the right bank downstream of Spur No. 3 was constructed before monsoon in the year 1943. The existing spurs were not maintained. Observations were made on the prototype during the monsoon season and are compared with the results obtained on the model.

River Beas remained high throughout the monsoon. The maximum flood experienced in 1943 was 380,000 cusecs at Dera Gopipur. The erosion of the left bank at the position of spurs has been observed on the prototype at different periods. Conditions at the spurs have also been recorded. A plot of the river edge as obtained at the end of September 1943, is shown in Fig. 13. An attempt is made to compare the model predictions in the presence of Spur C with the observations made on the prototype.

Model Predictions.	*Prototype Observations.*
It was shown on the model that :—	The observations made on the prototype in the beginning of September, 1943 show that :—

1. The head of Spur No. 3 would be outflanked. The shank would be washed away to a length equivalent to 640 feet from the head.	1. The head of Spur No. 3 has been outflanked and the shank has been washed away up to 450 feet from the head.
2. At Spur No. 2 shank would further erode by 880 feet and that the head of the spur would be situated on a high bela.	2. The shank of the Spur No. 2 has been further eroded by 930 feet. The head of spur is now situated on a high bela.
3. At Spur No. 1 no damage will occur to the shank or to the head.	3. No damage occurred at Spur No. 1 either to the head or the shank. A comparison of the river edge on the model and on the prototype at the end of 1943 is shown in Fig. 13. It will be seen from the erosion lines given in Fig. 13 that the agreement is close.
4. After the erosion of the left bank had occurred the main stream would shift well away from the left bank at the end of 1943. Along the bank the velocity would be very low.	4. The main river shifted away from the left bank. In fact very large bela formed downstream of Spur No. 1. The velocity was of the order of 1′-1·5′ per second.
5. Downstream of head of Alma Creek heavy erosion of the right bank would occur in the early floods. Later on a large bela would be formed there and the main stream would shift well away from the bank.	5. The right bank downstream of head of Alma Creek was first heavily eroded and subsequently the main stream shifted towards the left with the result that a bela formed there.

C. Optimum length, position and number of divide walls in a river pocket in order to control silt entry into a canal.

Various proposals regarding the number, length and position of divide walls to be constructed in the left pocket of the Kalabagh Headworks had been made. In order to arrive at the decision, model investigations were carried out.

The Model. A model of the River Indus four miles upstream and three miles downstream of the weir was constructed. The following scales were adopted :—

Horizontal :	Model to Prototype	1 to 100.
Vertical :	,, ,, ,,	1 to 15.
Exaggeration :		6·6.

SURVEY PLAN
OF
BEAS RIVER (1942 NOV.)
SCALE 4" = 1 MILE

1. THE PROBABLE POSITION OF DEEP CHANNEL IN THE PRES OF SPUR 'C' ....
2. THE PROBABLE RIVER EDGE OF THE LEFT BANK IN THE PR OF THE NEW SPUR 'C' ON THE RIGHT BANK ....
3. THE PROBABLE RIVER EDOE WITHOUT MAINTAINING THE SP.
4. THE PROBABLE RIVER CONL TIONS IN 1943 IF THE SPURS A MAINTAINED AND SHANKS CONSTRUCTED IN NEW POSITION

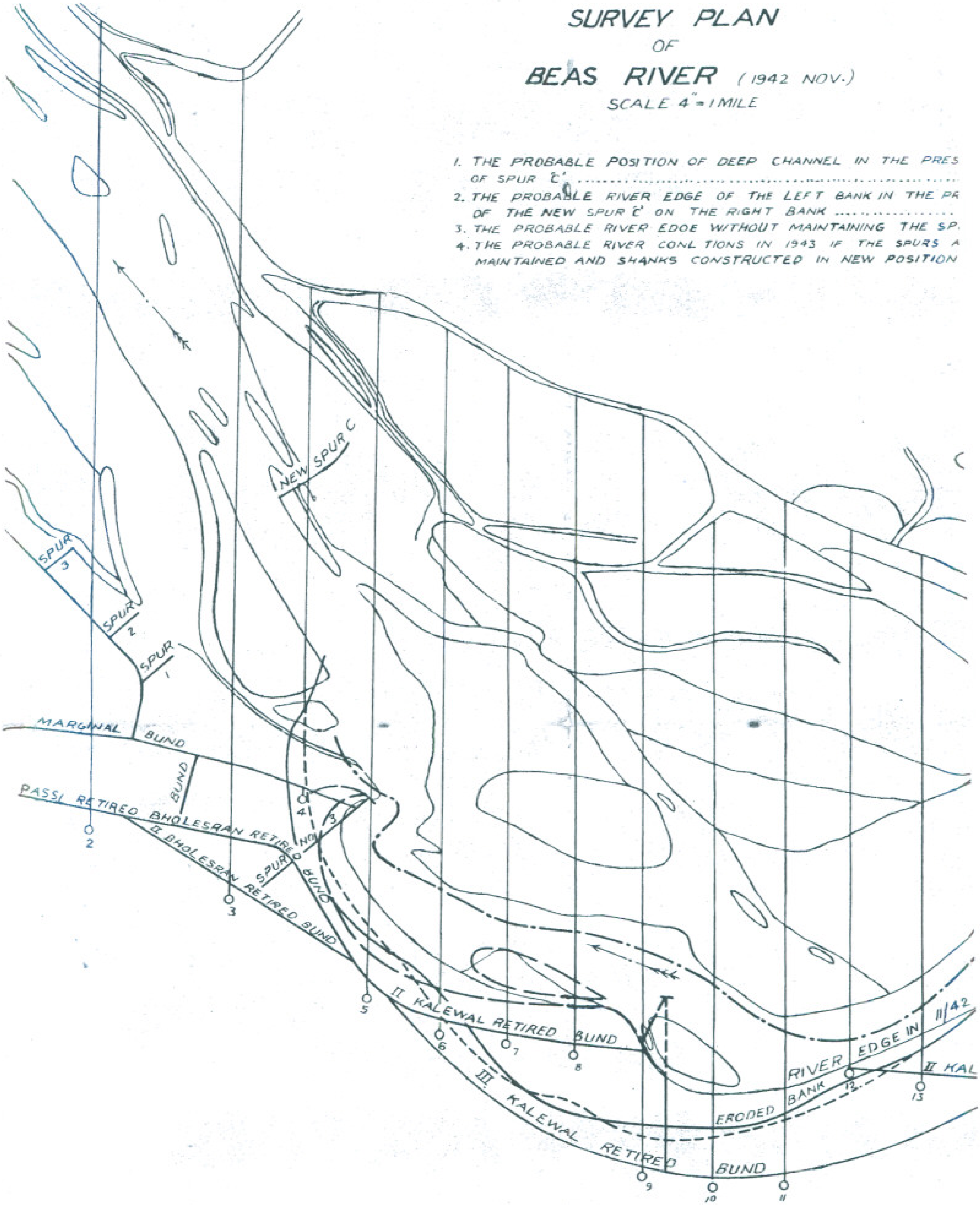
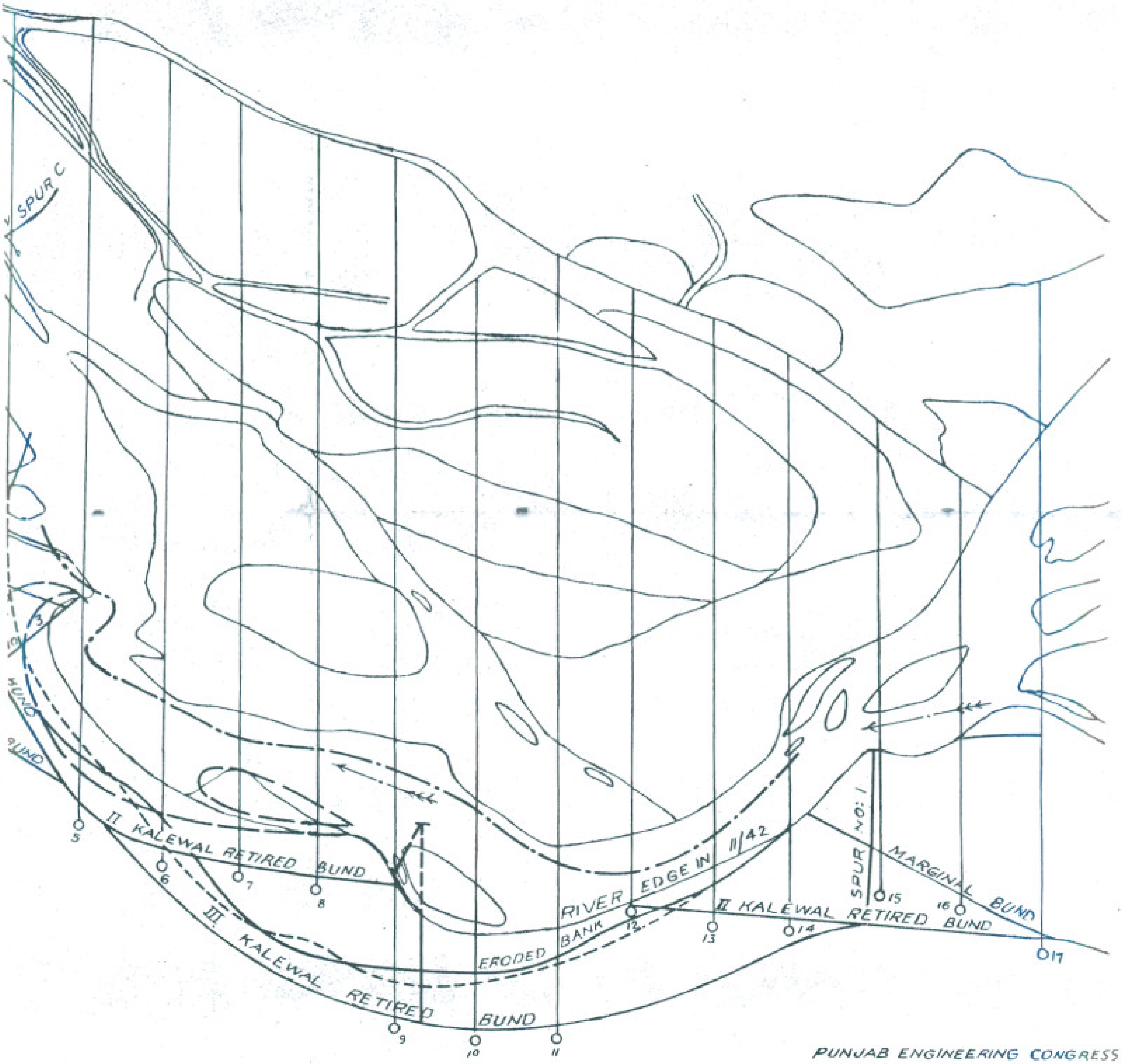


FIG. 12
PAPER NO 265

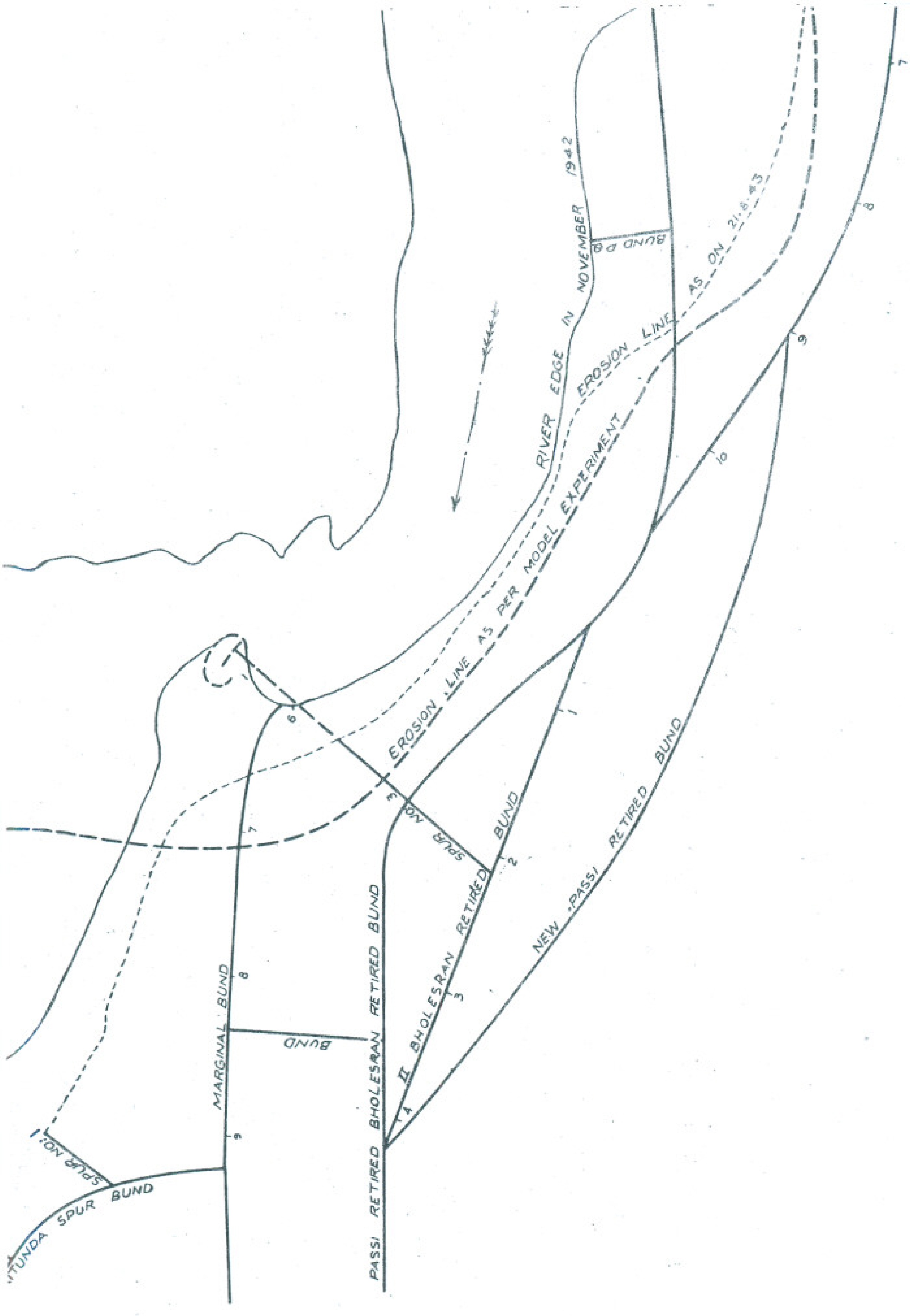
SURVEY PLAN OF BEAS RIVER (1942 NOV.)

SCALE 4" = 1 MILE

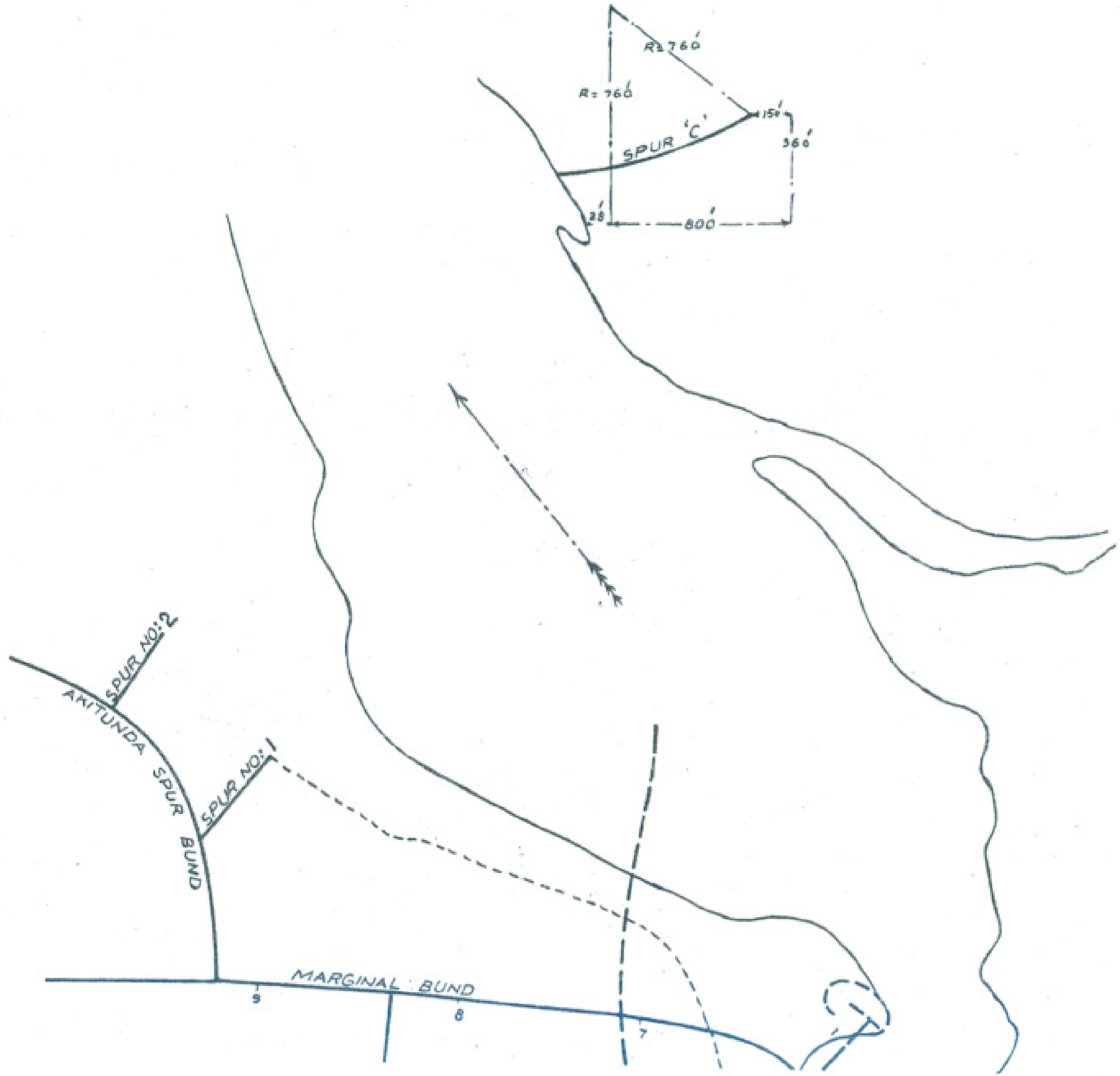
1. THE PROBABLE POSITION OF DEEP CHANNEL IN THE PRESENCE OF SPUR 'C' .... —·—·—
2. THE PROBABLE RIVER EDGE OF THE LEFT BANK IN THE PRESENCE OF THE NEW SPUR 'C' ON THE RIGHT BANK .... ———
3. THE PROBABLE RIVER EDGE WITHOUT MAINTAINING THE SPURS .... - - - - -
4. THE PROBABLE RIVER CONDITIONS IN 1943 IF THE SPURS ARE MAINTAINED AND SHANKS CONSTRUCTED IN NEW POSITION .... — — —



PUNJAB ENGINEERING CONGRESS
1944


RIVER EDGE IN NOVEMBER 1942
EROSION LINE AS ON 21.8.43
EROSION LINE AS PER MODEL EXPERIMENT
BUND PQ
SPUR NO 3
II BHOLESRAN RETIRED BUND
NEW PASSI RETIRED BUND
PASSI RETIRED BHOLESRAN RETIRED BUND
MARGINAL BUND
BUND
SPUR NO.1
TUNDA SPUR BUND

PLAN SHOWING ERC



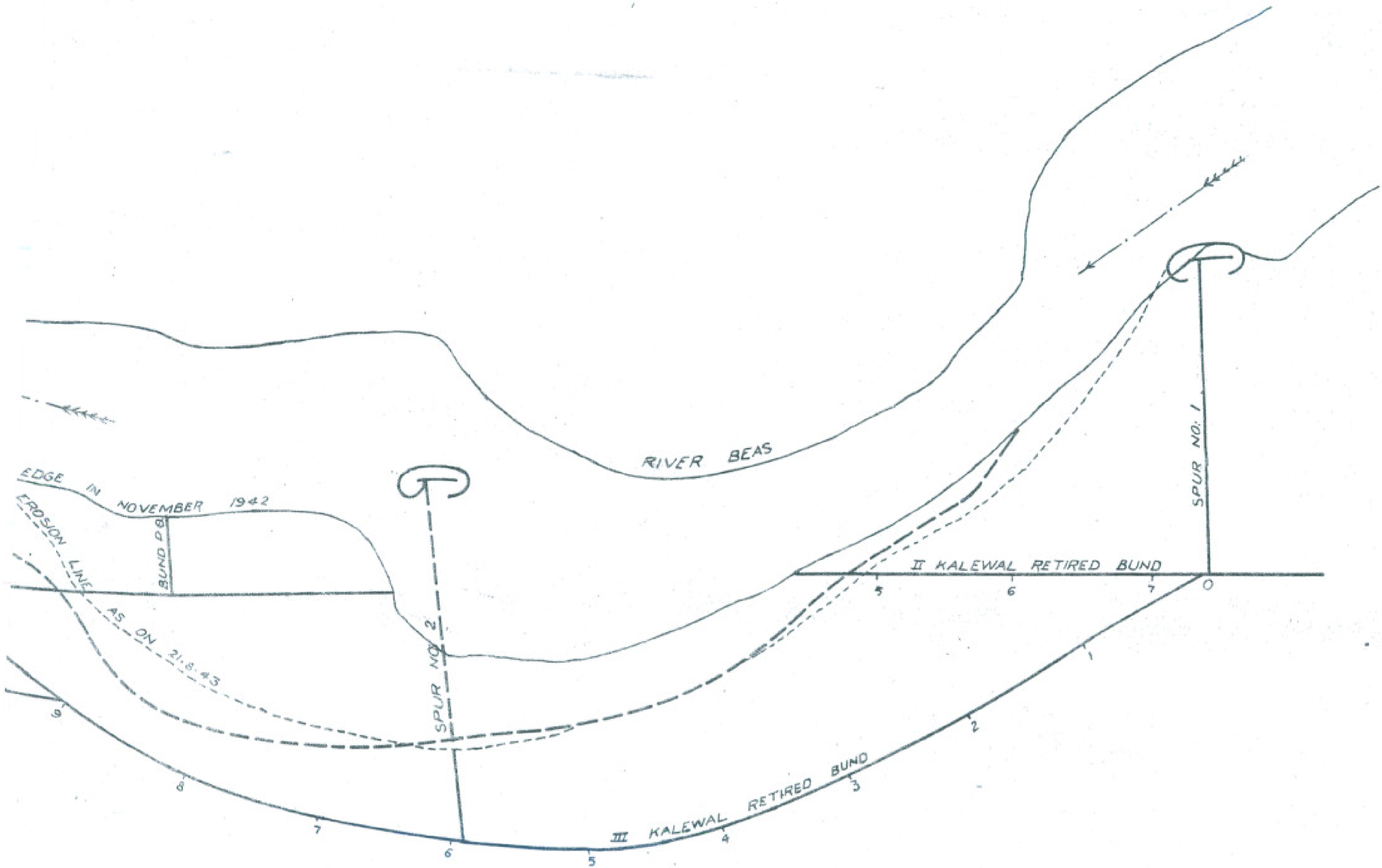

RIVER BEAS
SPUR NO: 1
SPUR NO. 2
II KALEWAL RETIRED BUND
III KALEWAL RETIRED BUND
EDGE IN NOVEMBER 1942
EROSION LINE AS ON 21.8.43
BUND D8
0
1
2
3
4
5
6
7
8
9

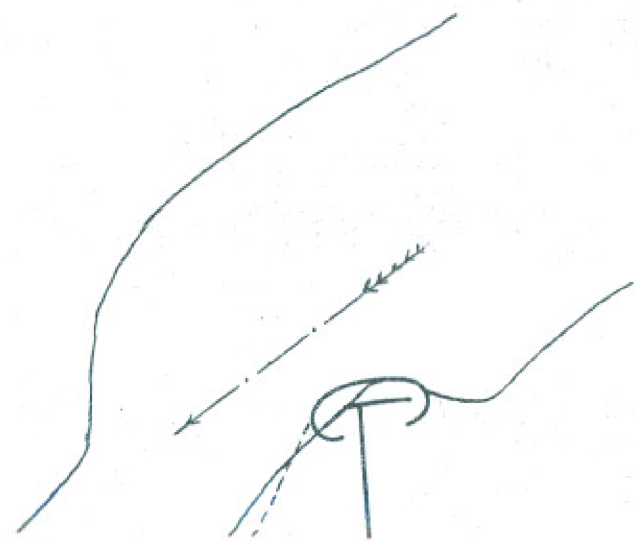
FIG. 13

PAPER NO: 265

ING EROSION OF LEFT BANK OF RIVER BEAS IN SPUR AREA

FLOOD SEASON 1943

SCALE 16" = 1 MILE



No additional tilt was used.

Bed Material. The bed on the model consisted of shingle and sand as at prototype.

The Items represented. The following items were represented :—

(*i*) The Kalabagh Weir.

(*ii*) The Undersluices and the Head regulator.

(*iii*) The guide bunds, the Nawab's bund and the marginal bunds.

Before carrying out experiments, with divide walls the river was diverted on to the weir by constructing leading cuts and the bunds. The model run for one season after diversion is shown in Fig. 14.

Experiments on the following lengths of the divide wall were carried out :—

(*a*) 600 feet long.

(*b*) 450 feet long.

(*c*) 300 feet long.

Two positions of the divide wall were examined :—

1. At the fourth pier of the undersluices.
2. At the seventh pier of the undersluices.

Detailed observations regarding the effect of position and length of the divide wall on the silt entering the canal, were made. Divide walls of the lengths 600 feet, 450 feet and 300 feet were constructed in the left undersluices at the fourth pier. A definite quantity of silt was added in the river at the nose of the left guide bank, and the silt in the canal and the river dowstream of the undersluices was collected in deep trenches. The discharges examined varied from 100,000 cusecs to 300,000 cusecs.

The quantity of silt added to the water in the river was 1 cft. per hour in 100,000, cs., 1·25 cft. per hour in 150,000, cs., 1·5 cft. per hour in 200,000 cs. and 2 cft. per hour in 300,000 cs. The quantity of silt collected in the river below the undersluices and the canal downstream of the regulator in four hours is shown below :—

Silt entry into the canal with different lengths of the divide wall for different river discharges in four hours.

Length of the divide wall.	100,000 cs. Silt in cft.		150,000 cs. Silt in cft.		200,000 cs. Silt in cft.		300,000 cs. Silt in cft.	
	Canal	River	River	Canal	Canal	River	Canal	River
600′	·31	·50	·60	·22	1·80	·67	8·57	4·2
450′	·77	·50	·32	·23	·72	·63	8.35	4·5
300′	·066	·102	·13	·195	·393	·57	7·6	4·32

From this experiment it will be seen that as the length of the divide wall decreases, the silt entry into the canal diminishes. The investigation showed that a divide wall 300 feet in length constructed at the fourth pier is preferable to either 450 feet or 600 feet in length.