PAPER No. 334

Training of River Loops and Currents on head Works

By

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Introduction.

Our rivers in the Punjab have been harnessed by the construction of weirs and Head works. The alluvial soils of West Pakistan are made up of the vagaries of the river action in the past over millions of years. Prior to the construction of weirs the rivers were free to select their own courses depending upon their own might. A river may continue to flow in a certain defined path for a number of years and then all of a sudden a big flood may completely change its course to an entirely new route. With this changing action of the rivers and the freedom of a river to change its course the lands of West Pakistan have been built up. Even to-day we come across the old courses of rivers Beas and Sutlej right from Qasur down to Multan yet their new courses are miles away from their old courses. The old courses of Chenab and Ravi are yet seen. With the construction of weirs, and Head-works the freedon of the rivers has been snatched from them and they have been made the slaves of man.

The usual layout of the weir and Headworks is shown in the Plate No. I. This is the device with which we have enslaved these mighty rivers. The Plan shows the layout of Marala Headworks.

The natural desire of a slave to regain his last liberty is well known. These enslaved rivers are no exception to this rule. The Irrigation Engineers have to constantly keep the river action subdued and keep the rivers under control. The rivers always try to get out of control in the following two ways ;—

(i) To breach the marginal bunds and outflank the weir. This is an attempt for complete freedom from control.

(ii) To create dangerous loops, change slope, cause erosion and damage works within the limits of the marginal bunds. I will call this action as a sort of internal agitation to cause trouble to the masters. In case that action of the river which takes place within limits of the marginal bunds is not taken notice

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of, this ultimately results in outflanking and thus river goes wild and out of control. Therefore the Engineers employed at Head Works are constantly fighting the river and make it adopt a desired route.

The author has been incharge of a number of Head-works in the Punjab in different capacities. He was a Sub-Divisienal Officer incharge of Marala Head-works, as Executive Engieeer incharge of Panjnad Head-works and as Superintending Engineer incharge of Khanki Head-works. In this parer the author has described certain important works in connection with the struggle of an Engineer to keep the rivers under control. It has been considered necessary by the author to print this experience so that the same is useful to the young Engineers for solving similar problems on Head-works and elswhere.

Marala Head-works.

This Headworks is located in the foot hills on the confluence of three important torrents :—

(i) Munawar Tavi on the right.

(ii) River Chenab in the centre.

(iii) Jammu Tavi on the left.

A reference to the plate No. I. will show that Munawar Tavi joins Chenab river from the right and the Jammu Tavi from the left. The slopes of these Tavies are more than that of the river itself. As such the velocities in the Tavis are higher than those in the main river. The silt carrying capacity of the Tavis is also much more, so much so that if Jammu Tavi carries a discharge of 30,000 Cusecs, the canal at Marala has to be closed lest it gets silted up. The Jammu Tavi runs along left marginal bund which is constantly in danger from the action of Jammu Tavi and has to be saved by keeping the course of Jammu Tavi well away from the Bund. In this paper important works carried out by the author to train the course of Jammu Tavis have been described in detail.

Floods of 1948 and 49.

Jammu Tavi has been eroding towards the U.M.B. opposite R.D. 26,000-29,000 since 1947. In 1947 the nearest point of erosion from the bund opposite R.D. 26,000-29,000 was 950′ which in 1948 shifted to about, 710′ *i.e.* (950-710=240,) *i.e.*, 240′, erosion took place in 1948 floods and there was severe erosion opposite R.D. 35,000. This was serious. To meet this situation a proposal for construction of retired embankment or construction of a hockey spur was made. These proposals were costly. An alternate proposal of putting in tree spurs in the loop and employing the current in *Gobindpur Drain* was made to silt up the loop and divert the current away from the Bund.

The Proposals.

(i) **Retired Embankment.**

A retired embankment was proposed from R.D. 21,500 to R.D. 30,300 of U.M.B. as shown in plate No. II. Keeping 25′

top width 5 : 1 inside and 3 : 1 outside slopes and an average height of 10-0′ above N.S. including free board, the approximate cost worked out to be Rs. 1,39,940. The other disadvantages of this proposal were :—

(1) More land had to be acquired for construction of the Bund.

(2) Three important village *i.e.*, Sagempur, Pallai and Ranidad will come on the river side and completely collapse in case the 1st line of defence gives way.

(ii) **Hockey Spurs**.

The other alternative was to construct a Hockey spur at R.D. 28200 as shown in the Plate No. II. This would cost approximately Rs. 75,000/-. The advantages of this proposal are evident. The stream at this site could be located at the head of this spur but this would cause many other pıoblems. The course of Tavis both U/S end D/S of this spure could still approach the bund in a dangerous manner. Construction of the hockey spur would mean inviting more trouble for future.

(iii) The current available in Gobindpur Drain was proposed to be diverted through a cunnette to meet the current in the loop at point A on plate No. II *i.e.*, opposite R.D. 34000.

A row of tree spurs was lowered in position 25′ apart. The arrangement of lowering the tree spurs is shown in the diagram No. 1

Alternative No. (iii) above was approved for execution at site. The details of cost of this work are given below. Tree of sizes that could conveniently be loaded in carts were transported to site and lowered in position and properly anchored by driving 4′ to 5′ long killas and tied squarely by a manilla rope 1″ dia. The head of the Tree spur should consist of enough number of branches and leaves so as to help in catching silt burden from the stream. Some of the spurs were washed away during 1948. These were replenished in 1949 and more spurs were also lowered in position. With proper watching no spurs washed away in 1949. The details of the cost incurred are given below.

Fixed tree spurs in loop of Jammu Tavi opposite R.D. 26-29

U.M.B. Detail of work.

No. of trees required for 1500 lenght $= \frac{1500}{25} + 1$ = 61 No.
at an interval of 25 feet.

No. of trees washed away = 14 No.

Total = 75 No.

Supplying pegs 3″ dia and 6′ long 75×6	=	450 No.
Driving peg 6′ long 3″ dia	=	450 No.
Supplying coir rope $\frac{61 \times 100}{450} = \frac{122}{9}$	=	13·6 Mds.
Carriage of rope lead 6 miles.	=	13·6 Mds.
Beldars for 9 months.	=	5 No.
Mate for 9 months.	=	1 No.

Analysis of rate of one No. tree 3′ to 4′ girth.

Approximate weight assumed to be 20 Mds.

1.	10 Cft. long wood @ 1/- per cft.	=	10/-/-
2.	7 Mds. fuelwood @ 19/-% cft.	=	1/5/-
3.	Carriage of 20 Mds. of wood lead ½ mile @ 1/4/-% Mn.	=	-/4/-
4.	Cutting and felling tree 20 mds. @ -/1/- per mds.	=	1/4/-
5.	Lowering spur into the water and fixing in position @ 5/-	=	5/-/-
6.	Add. D.A. @ 200/-% on item 4	=	-/8/-
7.	Add D,A. 100/.% on item 5	=	1/4/-
	Total	=	19/9/-

Fixing tree spurs in loop of Jammu Tavi opposite R.D. 26-29 U.M.B. Abstract of cost.

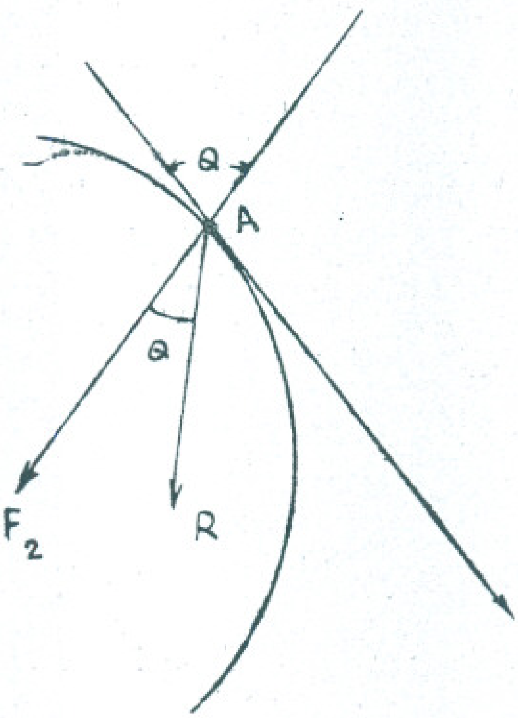
1.	75 No. trees @ 19/9 each	=	1467/-
2.	450 No. Supplying pegs 3 ×6′ long @ 2/-% No.	=	9/-
3.	450 No. Driving pegs as above @ 1/-% No.	=	4/8/
4.	13·6 mds. supplying coir rope @ 50/- per md.	=	680/-/-
5.	13·6 mds. C/o rope lead 6 miles @ 5/14 per md.	=	/13/-
6.	5 No. C.P. for 9 months @ 35/-P.M. per man.	=	1575/-/-
7.	1 No. mate for 9 months @ 41/- P.M. per mate	=	369/-/-
	Add D.A. @ 200/-% on item V	=	1/10/-
	Add D.A. @ 100% unit II and III	=	13/8/-
	Total	=	4120/7/-
	Add contingencies @ 3%	=	124/-/-
	Grand Total	=	4244/7/-

Action of Tree Spur.

Tree spur is a device shown in (Fig. I) lowered in position. This is an Obstruction put in the way of current to control the position of the current. The eddies created by the putting in of this obstruction pick up silt upstream of the spur and at the Head of the spur. The silt so picked up is deposited in the portion down stream of the spur due to reduction in velocity in this area. The phenomenon of p. king up silt up stream and its deposition downstream is shown in the Fig. 2. With this device in the rising flood the silting up tendency is created and if the spurs are kept firm in position the silting and scouring is caused as shown in this figure. The deep strean portion is shifted from the edge of the loop to the noze line of the spurs.

Action of currents meeting at an angle.

The figure shows an enlargement of the position at A; Plate No. II.



If V_1 is the velocity in the main current causing erosion on the loop, its direction will be in the direction of the tangent at A. V_2 is the velocity of the current employed to counter-act the action of V_1. V_1 and V_2 meet at A at an angle θ. If F_1 is the force in the current of loop and F_2 force in the employed current, then

$$\text{Tan}\,\theta = \frac{F_1 \sin\theta}{F_2 + F_1 \cos\theta} \quad \text{and} \quad R = \sqrt{F_1^2 \sin^2\theta + (F_2 + F_1 \cos\theta)^2}$$
$$= \sqrt{F_1^2 + F_2^2 + 2F_1 F_2 \cos\theta}$$

The above principle of emloying another current to deflect the direction of current causing erosion has been employed in conjunction with the principle of Tree spuring to check erosion in river loops.

The general shape of X-Section at a loop extending across the stream upto firm belas on both sides is shown in the Fig. 3. The deepest stream is at the edge of the loop, with a slope towards the bela on the inner side of the curve. The depth of water goes on reducing till it is zero somewhere near the inner bela edge which generally shows signs of silting up being on the concave side of the curve. With the introduction of Tree Spurs and the tendency of silting up near the edge of the loop the main deep current shifts its position at the noze of of the spur line in the rising floods. This action results in the reduction of the total flow area of the stream section. As such the current tries to make up the flow area which it has lost near the edge of the loop. This is done by eating up the slope of bed but the total flow area remains the same for the same discharge.

In the falling floods more silt is deposited near the edge of the loop and on the noze of the spurs. It is of great advantage to extend the noze of the Tree Spurs by adding another spur or if this is not possible due to some local conditions then by strengthening the same by staunching by brush wood. This is done to hold firmly the position already gained and also to achieve better results in the following freshets.

In the following freshets the same action is repeated. The deep current is now at the noze of the extended spur. More of bed on the inner side slopes is eroded and more of silt near the edge of the loop is deposited as is shown in the figure. This action goes on repeating itself with every freshet till the X-Section of the current is completely reversed as shown in the Figs. 3 and 4.

By adopting the above method of Tree Spurs the course of Jammu Tavi Main stream was shifted back by, about 1500' opposite R.D. 26000-29000 in 1948-49 and 40 feet land was gained by silting up. This was achieved at a cost of 4,244/7/-. The other alternative of making a second line of defence and a Hockery Spur were very expensive. This clearly illustrates the utility of the method adopted. The cost of the 3 alteruative methods is given below for the sake of comparison.

Retired Embankment	Rs. =1,40,000.
Hockey Spures	Rs. = 75,000.
Tree Spurs	Rs. = 4,244.

Experiments at Panjnad Headworks.

This method was adopted by the author in 1951 to save a serious situation on Panjnad Headworks. River Chenab has been eroding its right bank and threatened the right marginal bund. The minimum distance from the edge of loop to the U/S toe of R.M.B. was 185' in 1950 floods and in 1951 this distance was further reduced to 105' as is clear from the Plate

No. III. The situation had become very serious and we were not at all hopeful of saving the bund in 1952. Therefore all the shisham trees along the bund in the threatened reach was auctioned so that this property is not lost and taken away by floods. The town of Alipur and other neighbouring villages were informed of the coming catestrophy and were warned to run to places of safety in case the bund breaches and whole area is inundated.

Afther examining the site conditions the author decided to check the advance of erosion by putting in hanging Tree spurs. This was the last effort which we could make in such a hopeless situation. The arrangement of the spurs is shown in the plate No. III. Some of the trees which were being auctioned were used in this work. The total cost of the operations was Rs. 1184/- and to our astonishment the R.M. Bund was saved. The spurs proved to be very effective in the following floods also.

Estimate for providing Hanging Tree Spurs in River along R.M. Bund R.D. 52 to 54 at Panjnad Headworks.

DETAILS

1. No. of spurs provided at site as per total progress in the muster roll.		=82 Spurs.
2. Quantity of Fuelwood and timber used from plantation as per list of trees.		
	Fuelwood	=283 Mds.
	Timber	=577·25 Cft.
3. M.S. Wire used for tying the spurs, as per actual consumption at site.		=8 Cwt.
4. Manila rope used for carriage, rolling to river edge actually used.		=½ Cwt.
5. Labour charges as per muster roll.		=Rs. 175/8/-

ABSTRACT OF COST

283 Mds. fuelwood from plantation (credit to plantation)	@ -/4/- Md.	= 70-12-0
577·25 Cft. Timber from plantstion (credit to plantstion)	@ 1/-/- Cft.	= 577-4-0
8 Cwt. M.S. Wire (Stock Rate)	@ 40/- Cwt.	= 320-0-0
½ Cwt. Manila Rope	@ 160/- Cwt.	= 80-0-0
Labour charges	@ per actual	= 175-0-0
	Total	= 1223-8-0

Credit to estimate
½ Cwt. Manila Rope (used taken on return)
@ 80/-/- Cwt. = 40-0-0

Net Amount. 1183/8/-
Say Rs. 1184/-/-

Sometimes Tree Spurs can also be put in Kacha Bela.

1950 Floods had brought many changes in the course of Jammu Tavi at Marala. A very prominent change was visible in its course opposite R.D. 35000-41000. The Plate No. IV explains the position of the river both after the floods and before the floods. The dotted lines show the position of firm belas of 1949. The main current was flowing adjacent to these lines. The firm lines show the firm belas of 1950 opposite R.D. 37000-41000. The river eroded about 1000′ towards the bund from R.D. 37000 to 34000. The river completely abandoned its old course on the farther end of the central bela A and adopted a new direct course near the bund. This was a very unfavourable position as now the river was running very near the bund all along from R.D. 34000-41000 and further attack could make this whole length of the bund exposed to danger of a breach and outflanking of the weir. Something therefore was to be done to train the river back into its old course and keep it well away from the Bund.

The proposal.

The levels were examinad and it was found feasible to cut a small cunnette of about 10′ bed width through the firm bela B to join this cunnette with the old course of the river around the bela A as shown in Plate No. IV. This cunnette was dug in the low supply season. No attempt was made to divert this small discharge by making a bund in the narrow gullet at section C-C on account of the following considerations.

(i) Putting of a bund in running water would be expensive.

(ii) Any attempt to head up water by a bund may take the current away from this cunnette as the river bed here was very wide and consisted of Kacha sand bela. By heading up the tree spurs could be out flanked. It was decided to put a row of Tree Spurs as shown in the plate No. IV. Tree Spurs were anchoured on the Kacha bela and the only purpose of these Tree Spurs was to keep the current passing through section C.C. and keep it as close to the cunnette mouth as possible.

To start with a small discharge of about 10·0 Cusecs flowed in the cunnette and then as the discharge in the main river rose steadily the cunnette discharge started increasing. In the first freshet that followed the cunnette was carrying an appreciable discharge and started developing itself and finally the whole discharge of Tavi was diverted to its old course through the cunnette which automatically diverted itself in it.

The total cost incurred on this work is given below. In this way the river was trained back into its course of 1949 at a cost of Rs. 20,162/-. The cost of constructing a retired embankment wonld have been about Rs. 1,50,000. The advantages of the method adopted are therefore evident.

Estimate for laying tree spurs opposite R.D. 33000 and 41000 Upper Marginal Bund and digging cunnette the change the course of Jammu Tavi.

Number of Tree Spurs.

Opposite R.D. 33000.

Total length as shown on plan =2500 Lft.
Each spur being at 25' distance.

Therefore total spurs $\frac{2500}{25}=100$ No.

Opposite R.D. 41000.

Total length as shown on plan =3750 Lft.
Each spur being 25′ apart.

Therefore total spurs. $= \frac{3750}{25}=150$ No.

Material required for one spur.

Wood from plantation (in shape of tree)=20 Mds.

Wooden peg 3″ dia and 5′ long=2 No.

Manila rope L.S.

Abstract of quantities

1. Cutting and falling trees for plantation. $1\times(100+150)\times 20 = 5000$ Mds.
2. Carriage of spurs from site of cutting to site of laying, mean lead (1 ½)=3/4 miles = 5000 ,,
3. Lowering tree spurs at site 100+150 = 250 Nos.
4. Supplying wooden peg 3″ dia 5′ long $1\times(100+150)\times 2$ = 500 Nos.
5. Driving pegs = 500 ,,
6. Supplying manila rope 1% dia for fixing tree spurs. = 15 Mds.
7. Watching establishment for 9 months 10 beldars and one mate for trees spurs opposite R.D. 33000 & 10 beldars and one Mate for tree spurs opposite R.D. 41000. Therefore total Mates for 9 months 1+1=2 Nos.
   Total beldars for 9 months 10+10=20 Nos.

8. Jungle clearance at site of digging cunnette $\frac{1\times2350\times50}{4840\times9}$ 2·70 acre

9. Earth work dry undressed lead 100′ as per detail sheet 376000 Cft.

10. Earth work wet undressed lead 125′ 235000 ,,

11. Earth work slush undressed lead 150′ 33000 ,,

Estimate for laying the Spurs opposite R.D. 33,000 and 41,000 Upper Marginal Bund and Digging Cunnette to change the course of Jammu Tavi.

No. of Quantity	Datail of Items	Rate	Per	Amount
5,000 Mds.	Cutting and felling trees from plantation -/1/- 100%	0-2-0	Md.	625-0-0
5,000 Mds.	Carriage of Tree Spurs from site of cutting to site of laying mean lead 3/4 miles 1/8/- 200%	4-8-0	% Mds.	225-0-0
250 No.	Lowering Tree Spurs at site	5-0-0	each	1250-0-0
500 No.	Supplying wooden pegs 3″ dia 5′ long. 1/4/- 100%	2-8-0	,, No.	12-8-0
500 No.	Driving wooden begs 3″ dia 5′ long 1/8/- 100%	3-0-0	,, No.	15-0-0
15 Mds.	Supplying Manila Rope	48-8-0	Mds.	727-8-0
2 Mates	For watching tree spurs for 3 months. 18/- 26/- 3/-	47-0-0	Each M.	846-0-0
20 Beldars	For watching Tree Spurs for 9 months. 15/- 26/-	41-0-0	,,	7380-0-0
2·7 Acres	Jungle clearance (Heavy Jungle) 10/- 100%	20-0-0	% Cft.	54-0-0
376000 Cft.	Earth work dry undressed lead 100′ 3/6/- 200%	10-2-0	% Cft.	3807 0-0
235000 Cft.	Earth work wet undressed lead 125′ 5/8/- 200%	16-8-0	,,	3878-0-0
33000 Cft.	Earth work slush undressed lead 150′ 7/10/- 200%	22-14-0	,,	735-0-0
				19,575-0-0
Rs. 19575	Add Contingencies	3-0-0	%	587-0-0
		Grand total		20,162-0-0

Marala Division,

Detail of Earth Work Quantities

R.D.S.	Earth Work Dry			Length	Contents	Earth Work Wet		
	Area of X. Section	Total Area of X. Section	Mean Areas			Area of X. Section	Total Area	Mean areas
0	216·00	—	—	—	—	208·56	—	—
250	200·10	416·10	208·00	250	52006	150·35	358·91	179·46
500	194·70	394·80	197·40	250	49350	131·73	282·08	141·04
750	195·00	389·70	194·85	250	48713	131·86	263·59	131·79
900	146·00	341·00	170·50	250	42625	104·70	236·56	118·28
1150	136·00	282·00	141·00	250	35250	70·40	175·10	87·55
1400	138·00	274·00	137·00	250	34250	75·32	145·72	72·86
1750	128·00	266·00	133·00	250	33250	35·50	110·82	55·41
2000	136·00	264·00	132·00	250	33000	78·40	113·90	56·96
2250	134·00	270·00	135·00	250	33750	64·40	142·80	71·40
2350	136·00	270·00	135·00	100	13500	67.40	131·80	65·90

375694 say 376000 cft.

(i) Jungle clearance $\frac{1\times 2350\times 50}{4840\times 9}$

(ii) Earthwork Dry undressed lead 100′

(iii) Earthwork Wet undressed lead 125′

(iv) Earth Work Slush undressed lead 150′

U. C. C.

For Digging Cunnettes.

Length	Contents	Earth Work Slush			Length	Contents
		Area of X. Section	Total areas	Mean areas		
—	—	14·0	—	—	—	—
250	44865	14·0	28·0	14·0	250	3500
250	35260	14·0	28·0	14·0	250	3500
250	32946	14·0	28·0	14·0	250	3500
250	29570	14·0	28·0	14·0	250	3500
250	21888	14·0	28·0	14·0	250	3500
250	18215	14·0	28·0	14·0	250	3500
250	13853	14·0	28·0	14·0	250	3500
250	14238	14·0	28·0	14·0	250	3500
250	17850	14·0	28·0	14·0	250	3500
100	6590	14·0	28·0	14·0	250	1400

235275 say 235000 cft.

32900 say 33000 cft.

: 2·7 acres

: 376,000 Cft.
: 2,35,000 ,,
: 33,000 ,,

Experiments at Khanki.

In early August 1956 due to changes in river courre below Alexandra Bridge at Wazirabad, armoured heads of spurs I lower Arm and I-Middle Arm became the target of serious action of Chenab River. The river discharge in the early stages of these developments was between 73000 to 261165 Cusecs. In the rising floods of 1956 summer the river course between Alexandra Bridge and Khanki Headworks changed a good deal and the major change was noticeable in shifting of main river stream very near the spurs I Middla Arm and I lower Arm. The confluence of river and tail U.J.C. stream which outfalls in the main river thus shifted up and spurs I.Middle Arm and I-Lower Arm came under direct river action. The river action on the spurs is shown in Plate No. V. The scour against the spur heads measured upto 45 feet depth.

The action of currents on the I Middle Arm and I Lower Arm spur Heads is explained on Plate No. V. A very strong current approached the Head of spur I Middle Arm, caused a Free Vortex at point A and a negative vortex at point B. Then the current moved out to hit at head of spur I lower Arm, caused a Free vortex at point A′ and a negative vortex at point B′.

Action of Free Vortices at A & A′.

Free spiral vortices were formed at points A & A′ near the spur Heads. The column of water rotated round a centre and moved inwardly into the come of the Cylinder, caused in a spiral motion. The intensity of pressure being minimum at the inner radius and maximum at the outer radius, the rotating Cylinderical spiral vortex caused suction on the botton end of the core and also caused churning of the material at the bed. This caused heavy scour which extended upto 45′ in this particular case and would have been much more if it was not checked in time.

Action of Negative Vortices at B & B'.

The motion in the liquid is caused by the force transmitted from the radial flow from the main current. This causes the liquid to move with an angular velocity and the conditions similar to those of a forced vortex were obtained. The angular velocity on the outer radius causes-erosion of the banks and embayments are caused as shown in the Plate V. Another interesting phenomena was noticed here on the D/S of 1 Middle Arm the water enters the embayments from D/S side and leaves on the upstream side i.e., the motion of the liquid is clockwise. On the U/S of 1 Lower Arm the water enters from the U/S side and after completing the round leaves in the D/S side i.e., the motion of the liquid is Anti-clockwise. This in fact depends on the direction of the radial flow from the main current.

Due to the scour caused by Free vortices, the stone aprons suffered considerable settlement which was recouped by dumping stone in wire crates. Due to the negative vortices embayments were formed. The most serious threat to the training works rose out of the embayments upstream of I-Lower Arm and downstream of I-Middle Arm. The extent of embayment and flow conditions are shown in plate No. V.

The embayment immediately downstream of I-Middle Arm became serious in the first instance threatning the spur shank in position KK. This embayment almost touched the toe of pitching. Heavy erosion, scour and falling of sides continued unabated with heavy swirling. The action was checked by anchoring a tree spur in position A to kick off the back water current. This Tree spur consisted of a full 5 feet girth tree with trunk fixed on the river edge as per method shown in Fig. 1. The Tree trunk was held in position by strings, stakes, and guy ropes fastened to strong stakes on the bank. The Tree spur was weighed down at Head with loose stone and brush wood, in alternate layers and made secure. This Tree spur resulted in deflecting the current flow away from river edge.

The following brushwood spurs were put in position 1, 2, 3, 4 to 6 and there spurs induced silting. These spurs consisted of alternate layers of brushwood and stone to weigh them down. The total length of subsequent Spurs was less than the 1st Key spur. The main Tree spur at A alone was under river action and had to be kept strengthened and roped in position. The subsidiary brushwood spurs acted only to induce These arrangements stopped further erosion at once and induced silting. silting.

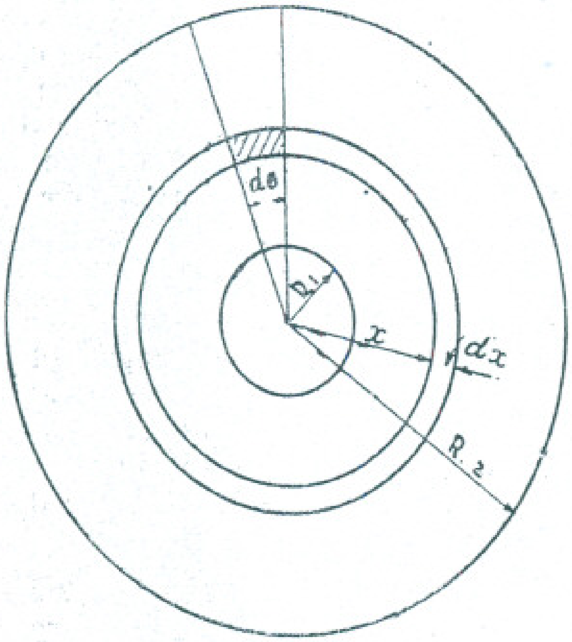
To watch the results X-Sections were observed along line 1/1, 2/2 and 3/3 on different dates. The X-Section Plates VI and VII are attached and indicate the positive result of position. Towards end of September the entire embayment silted up and flow became straight. No further action took place later.

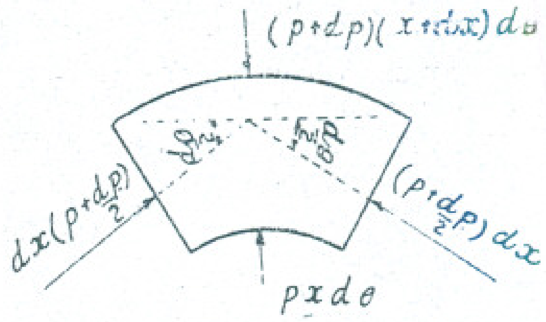
Immediately upstream of the 1-Lower Arm, embayment was formed, as shown in Plate V. The problem was tackled on the same lines as stated above. A strong tree spur was put in position M to deflect the current and reduce action on the bank. Subsidiary Brushwood spurs 1 to 7 were then put in to induce silting. X-Section were observed on line 1/1, 2/2 and 3/3 on various dates to watch the result. These X-Sections are attached and show that further action was stopped. By end of September the embayment silted heavily and flow straightened.

The arrangement of main tree spurs and brushwood spurs was found of immense advantage and yielded wondeful results. The protection was afforded cheaply and quickly. Had these steps not been taken the spur shanks 1-Middle Arm and 1-Lower Arm would have been washed away and in succession all other spur shanks would have been breached and Headworks out flanked. The plotted results of silting action Plates VI and VII as induced by tree spurs at Khanki conform exactly with the results plotted in Fig: 3 and 4 of Marala Headworks and afford a conclusive proof of the effectiveness of this method.

River Loops and Embayments-how Formed.

Reference may please be made to plan of 1950 plan VII and the conditions of the loop around the Bela A be considered. This loop more or less conforms to the shape of a portion of a circle of radius R with centre at A. Consider a condition of no velocity in the loop and assume it to be an annular ring revolving around the centre A with an angular velocity w.





Let R1 and R2 be the internal and external radii edges of the loop containing water flowing with an angular velocity w. Consider a thin ring of liquid of radius x and thickness dx. Consider a portion of this thin ring subtending a small angle $d\theta$ at the centre and let p be the intensity of pressure on the inside of the element due to centrifugal force. Then the centrifugal pressure will increase by dp over the thickness of ring dx. Consider the whole loop to be of unit thickness in the place of paper.

Area of the inside of element	$= X\, d\theta$
Area of outside of element	$= (x+dx)\, d\theta$
Area of the sides of the element	$= dx$
Intensity of pressure on the sides of the element	$= p + \frac{dp}{2}$
Intensity of pressure on outside of element	$= p+dp$
Weight of element	$= w\,(xd\theta)\, dx$
Centrifugal force on element	$= \left(\frac{wxd\theta\ dx}{g}\right) w^2 x$

*Proof from Hydraulics by Lewitt.

The normal forces due to the pressure of the liquid along with the centrifugal force keep the element in equilibarium. Resolving radially and assuming the sine of a small angle to be equal to the angle in radians.

$$pxd\theta - 2\left(p+\frac{dp}{2}\right) dx \, \frac{d\theta}{2} + (p+dp)\,(x+dx)\, d\theta$$

$$= \frac{wx \, d\theta \, w^2 \, xdx}{g}$$

Dividing by $d\theta$ and ignoring all small quantities of the second order $dp = \frac{w \, w^2 \, x \, dx}{g}$

Integrating between R1 and R2 centrifugal intensity of pressure

$$= \int dp = \int_{R_1}^{R^2} \frac{w \, w^2 \, x \, dx}{g}$$

$$\frac{w \, w^2}{2g} \left(R_2^2 - R_1^2 \right)$$

Centrifugal Head or as $v1 = wR1$ and $v2 = wR2$, $\frac{p}{w} = \frac{w^2}{2g} \left(R_2^2 - R_1^2 \right).$

$$\text{centrifugal Head} = \frac{v_2^2}{2g} - \frac{v_1^2}{2g}$$

The loop under action therefore conforms to the conditions obtained on a Forced Vortex.

The centrifugal Head impressed on the liquid is mainly responsible for the damage, causing erosion and scour. Assuming that velocity on the inner radius of the loop is zero than the centrifugal Head $= \frac{(v_2)^2}{2g}$

i.e. $H \propto v^2_2$

It is directly proportional to the square of velocity on the outer radius i.e., on the edge of the loop. The action of this angular velocity on the circumference of the loop is to undermine it. When undermining proceeds sufficiently the sides fall into the current and then are carried away in the direction of the current. This action is responsible for erosion of banks of the rivers. As is evident from above the only factor responsible for this evil is the velocity on the outer radius of loop. As such whatever device we use to check such action should be to reduce the velocity on the outer edge.

The following methods are most effective.

(i) To employ velocity in one stream to kill the velocity in the other stream.

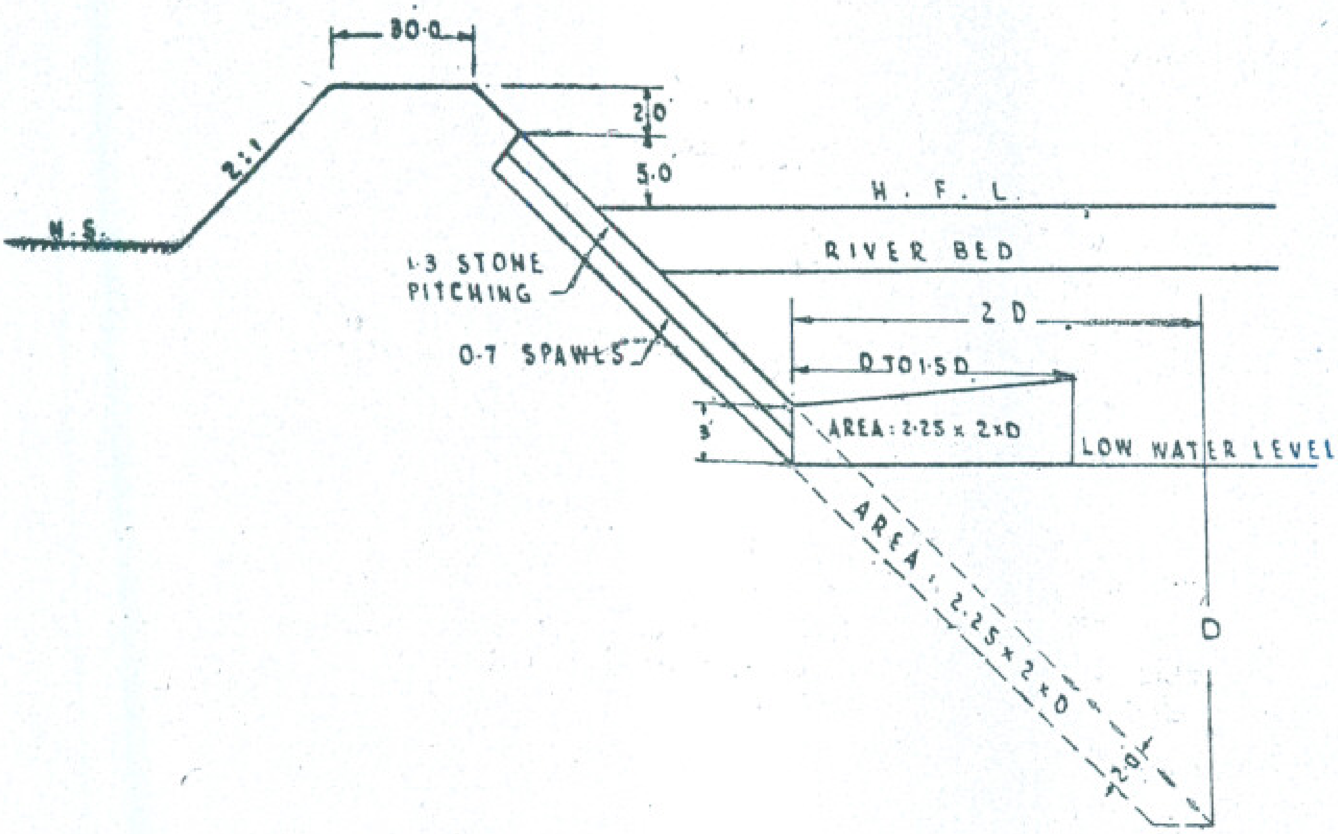
(ii) To use tree spurs for reducing velocity and inducing silting up of loop.

(iii) Combination of (i) and (ii) above.

These methods are far more useful than making permanent spurs, groynes or retired embankments etc, and are less expensive.

Damage to Aprons.

Aprons are provided on spur heads, guide banks and on upstream and down stream sides of weir. These aprons are provided to make the works safe against scour. The prevalent design of an apron is illustrated in the figure below :—



These aprons are designed against the highest anticipated scour. The highest anticipated scour D is calculated from the kennedy's regime flow formula *i.e.*, $Vo = 0{\cdot}84\ D^{0{\cdot}64}$

$$q = \text{Velocity x depth}$$

$$= \text{C.V.R. x } 0{\cdot}84 D^{0{\cdot}64} \text{ x } D$$

$$= \text{C.V.R. x } 0{\cdot}84\ D^{1{\cdot}64}$$

$$D = \left(\frac{q}{\text{CVR x } 0{\cdot}84}\right)^{\frac{1}{1{\cdot}64}}$$

Although such aprons are designed for the highest scour depth yet almost every year the aprons get damages by the action of strong currents. This phenomena is well known on all Headworks. Such damages ocur on account of the

1. Scour caused by straight unobstructed flow.
2. Scour caused by deflected currents.
3. Scour caused by swirls etc.

The 1st two categories of scour are normal and occur olmost every year on each Headworks. This causes the settlement of aprons which are replenished almost every year. This type of scour is not dangerous and is generally not taken notice of during the floods. The repairs are carried out annually after the floods are over. However at times even this type can be dangerous. In 1950, 147 No. P.C.C. blocks of 5′ x 5′ x 2′ size were bodily lifted from D/S of bay No. 4 of Marala Headworks and taken away by strong current. We could not find even the trace of these blocks which were deposited in the scour hole down below. It was fortunate that weir remained safe. These blocks were later replaced.

The worst type of scour occurs when swirls are formed in the vicinity of aprons. The scour holes can extend upto 100′ or more. The process of the scour caused by swirls is explained as below :—

In the case of a Free Cylinderical vortex the streem lines move freely in horizantal circles and the variation of total energy across the streem lines is zero.

$$i.e.\ dE = o$$

$$\text{Now } \frac{dE}{dr} = \frac{v}{g}\left(\frac{dv}{dr} + \frac{v}{r}\right)$$

$$\text{If } dE = o$$

$$\text{Then } \frac{v}{g}\left(\frac{dv}{dr} + \frac{v}{r}\right) = o$$

$$\text{Log}_e{}^{v} + \log_e^{r} = c$$

$$\text{then} \quad vr = c$$

$$v = \frac{c}{r}$$

C is called the strenght of vortex ; applying Bernoullies equation to any two horizantal concentric stream lines.

Let radii be r_1 and r_2 and pressures be p_1 and p_2

$$\frac{P1}{w} + \frac{v1^2}{2g} = \frac{p^2}{w} + \frac{v2^2}{2g}$$

$$\text{Then } \frac{p1 - p2}{w} = \frac{v_2^2 - v_1^2}{2g}$$

But $v1 = \frac{c}{r1}$ and $v2 = \frac{c}{r2}$

$$\frac{P1-p2}{w} = \frac{c2}{2g}\left(\frac{1}{r_2^2} - \frac{1}{r_1^2}\right)$$

The above equation gives the pressure head difference between the two stream lines of a Free vortex.

As is evident from the above equation the curve representing the variation of pressure will be a parabola and in an actual vortex we find that the shape assumed by the free liquid is also a parabola, the outer edge being higher than the inner edge. Since the pressure at the outer radius is more than the pressure at the inner radius, the liquid also flows radially inwards towards the central core of the vortex. In actual practice therefore a Free Cylindrical vortex is never formed. It always converts itself into a free spiral vortex. The core of the spiral vortex so formed causes a suction pressure on the other end of the core, which is the bed of the river. The suction pressure so caused accelerates the process of scour by lifting the material from bed. This material is washed off by the centrifugal velocity near the bed. The material from the U/S side cannot enter the pit as the circular velocity in the swirl does not allow the particles from outside to enter the scour pit. If this scour occurs in the vicinity of an apron, this soon gets damaged. Such a type of scour is most dangerous and whenever noticed during the flood should at once be tackled without waitings, as in case of delay this can be disastruos. This type of scour was noticed in August, 56 on I Middle Arm Spur Head in Khanki Headworks.

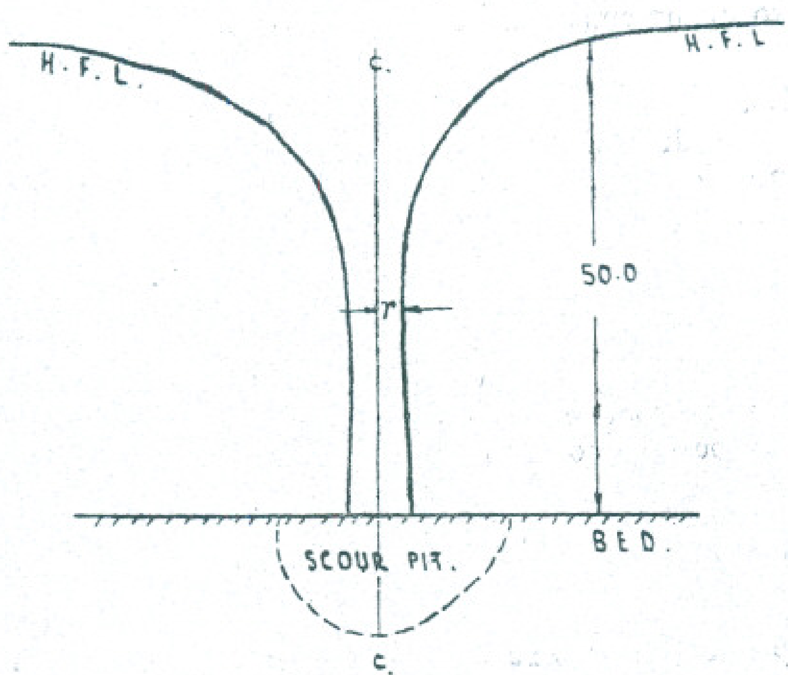
The planning to check this evil should be based on the principle that the scouring action of the vortex be arrested and stopped and further to this an attempt be made to make the vortex disappear.

To check scour the best thing is to fill the scour hole and reduce the scour depth. Dumping of loose stone will be of no advantage as the loose stone pieces will not be sufficiently heavy to settle down in the scour pit. According to the specification the loose P. Stone is to weigh not less than 16 Lbs., and the maximum size is to be determined is that can be conveniently handled by an average person say about 25 Lbs.

Take the case of a swirl with inner redius r and 50' depth of water from H.F.L. to bottom.

The up lift pressure caused at the bottom/Sft, =64x50=3200 Lbs/Sft., and stone weighing 16 Lbs., to 25 Lbs. will not be able to settle down in the scour pit in view of such a tremendous suction and uplift pressure. Therefore to be uble to fill the scour pit in such circumstances the stone to be dumped should be filled in crates. Let the crate size be say 2' x 3' x 4'

Weight of crate filled with stone (2 x 3 x 4)×150=3600 Lbs.



This stone crate will be able to settle down in the scour pit which is under an uplift and suction pressure of 3200 Lbs/ sft and therefore crates of this size be dumped in the scour pit.

The filling in of the pit by non-erodible material will reduce the suction pressure on the bottom of the core of the vortex and this in turn will reduce the strenght of the vortex and as the dumping of P. Stone crates proceeds we will find that the vortex will disappear gradually. This method was adopted by the author to fight the vortex formed on the Head of I Middle Arm Spur at Khanki Headworks in August, 1956.

Merits and demerits of Armoured Spurs and Tree Spurs

Temporary Tree Spurs	**Permanent Armoured Spurs**
1. These are very cheap and easy to construct.	1. These are very expensive and comparatively difficult to construct.
2. Tree Spurs do not reduce the area of Flow of a river betwen the marginal bunds.	2. The shanks of the armoured spurs are tied with marginal bunds and thus the area of Flow of the river between the marginal bunds is reduced.
3. Tree Spurs induce silting and are effective in reversing the X-Section of Flow at the site where these are used.	3. Armoured Spurs attract current, cause scour near their heads and keep the current permanently near their heads.

4. Tree Spurs do not cause any embayments rather these are used to silt up embayment.

4. Armoured Spurs cause swirls and embayments and their shanks remain in danger of being outflanked.

5. Tree Spurs are used to train the river course at a particular site and they do not create any adverse problem subseqently.

5. Armoured Spurs keep the current attracted at their hcad but create subsequent problems at other points both U/S and D/S. This result in construction of more and more spurs till we have a chain of spurs on both banks of the river.

6. When the problem is over the tree spurs do not require any maintenance. In fact trec trunks, guy ropes and stakes can be recovered after the problem is over.

6. Armoured spurs Head, aprons and shanks need to be kept to design section constananly and thus their maintenance is very expenseive.

Important Thumb rules to be kept in view while putting in Tree Spurs.

1. The Tree Spurs should be anchored on the firm bela *i.e.,* the bela or land being eroded by the current. These should not be anchored on the kacha bela as the same are likely to be out flanked and thus washcd away.

2. The first spur should be sited at a point where the current just enters the loop. This point can easily be determined by visual inspection of site. This may be called the "Key Spur".

3. The Key Spur should be about 5′ to 10′ longer than the subsequent spurs and as far as possible be placed at right angles to the direction of the current,

4., The sebsequent spurs should be placed 25′ apart and at right angles to the current if possible but they may also be placed at an angle of 75° to the direction of current.

5. The head of the spurs be made heavy. If the trees are not sufficintly heavy, stone may be added to increase weight, so that the head of the spur can settle in position and induce silting.

The base of the Tree Spurs be ancho red properly by driving wooden stakes across it. The same should also be tied with manilla rope or G.I. Wire. This is necessary lest the tree spur is washed away by the current.

7. After every freshet the position be re-examined. The missing spurs if any be replaced. If possible the noze of the spurs be extended suitably or brush wood filled so as to induce more silting in the following freshets.

Effects of Meandering.

A reference to plate No .I will explain the position of various currents approaching the headworks' Munawar Tavi joins at the head of right guide bund' the Chenab is kept in the right an and Jammu Tavi in the center. This type of arrangement ensures best regulation and even distribution over the weir crest and avery efforts is made to maintain this position at this head works.

During early floods of 1950' Munwar Tavi brought down a considerable discharge and formed a cut off to Join the main river at point A instead of joining at head of right guide bank. This change of meandering in the Munawar Tavi had an adverse effect on the Headworks.

The author was incharge of this headwork. One morning we found an abnomal concentration of discharge on the left bays of the weir. The main current instead of being in the right arm was directly hitting the canal Head Regulator and the concentration of discharge was in Bay Nos. 1, 2, 3 & 4 while Bay. Nos. 5, 6, 7 & 8 were passing very little discharge. The author, therefore, inspected the river conditions in a motor launch. It was found that Munawar Tavi was in flood and was joining the main river at Point A instead of the usual confluence poini i.e., the Head of right guide bank. These two cnrrents i.e., Chenab and Munawar Tavi were meeting at right <s approximately and this action had caused the formation of a silt bar across the cross-section of the right arm channel. All the flow of the river Chenab and Munawau Tavi had been diverted to the left side through the central arm of the river. The silt bar was so much high that a boatman was able to walk over it. The depth of water over this silt bar was only 1·5′.

To restore the main current in the right arm, Bay Nos. 1, 2 & 3 were lifted up and under sluice gates and canal gates were closed. This caused an appreciable afflux head ranging from 2·0′ to 2·5′. The onslaught of the fast current was checked ; and due to heading up more discharge passed over the silt bar. The bays Nos, 8, 7, 6, 5 & 4 were worked which attracted more river discharge. The silt bar was thus washed away and the main current was trained back into its old position. This was of course a departure from the printed Regulation Rules.

Meandeaing of river has got to be carefully watched both upstream and down-stream of the Headworks. At present our annual river surveys at Heayworks do not properly deal with the river conditions D/S. The slope, the Khadir width, and the extent of meandering of a river varies as it flows from the foot hills down to sea. The slopes generally vary from 3′ per mile in the foot hills to about 3″ per mile naar the sea. The Khadir widths vary from ½ miles near the foot hills to about 8 miles near the sea. Some data was collected by Mr. J.E. Spring to determine the extent of meandering of the rivers in India. The meanding generally varies from 8% near the foot hills to about 40% near the sea in alluvial rivers. The following table shows the extent of meandering of river Indus as calculated by Mr. J.E. Spring.

Successive 100 miles lengths		Length measured Fairly direct	Length measured round bend	Percentage of meandering
1st 100 miles beginning at sea		72	100	39
2nd	-do-	75	100	33
3td	-do-	72	100	39
4th	-do-	69	100	45
5th	-do-	82	100	22
6th	-do-	82	100	22
7th	-do-	93	100	7
8th	-do-	98	100	2
9th	,, near Kala-bagh	97	100	3

The above table shows that extent of meandering in Indus near Kalabagh is only 3 % while near sea it is 39%. Consider a stage of alluvial river where slope is about 1·5 Per mile and meandering is say 20%, In a certain flood the meander bends are straightened. This straight enining of the meander bends is likely to cause a scour of 0·6' immediately below the weir. The scour below the weir may extend to about 3′ to 6′ in case 10 to 20 miles length of the river is fairly straightened due to the meandering action. Similarly if a fairly straight reach of a river assumes about 20% meander bends, a corresponding silting up of the D/S of weirs will result. As such the effect of meandering of rives above or below a weir is not to be ignored. At present detailed river surveys are not carried out below a weir. It is recommened that river surveys below weirs shoulds extend upto about 5·0 miles D/S so that a proper picture of the river long section is studied every year.

Cocnlusion.

The foregoing studies will elucidate that it may not be adviseable to construct permanent spurs, groyns or pitched Island in that stage of the river where Khadir widths are narrow, slopes are steep and percenaget of meandering is low, i.e.near the foot hills or at a stage when the river just enters the plains. Any permanent structure made here will reduce the Khadir width and percentage of meandering, and incerease the slopes correspondingly. This may cause high velocities which are dangerous for works constructed on river beds. In this stage of the river the Marginal Bunds should envelope the known Khadir widths and should be strong enough to stand against the highest flood level. The training of various loops and currents within the marginal bunds be done by the method described in this paper.

When the river flows on the plains, the slopes decrease to about 1 foot per mile or less, the Khadir widths increase to say 1 mile to 10 miles, the percentage of meandering also increase to say 20% or more. The velocity in the stream correspondingly decreases and at such a stage for training purposes the use of permanent spurs, groyns or pitched I slands will be adviseable because their constructions will neither restrict the flow area nor increase the valocity to any dangerous extent.

FIG. 1

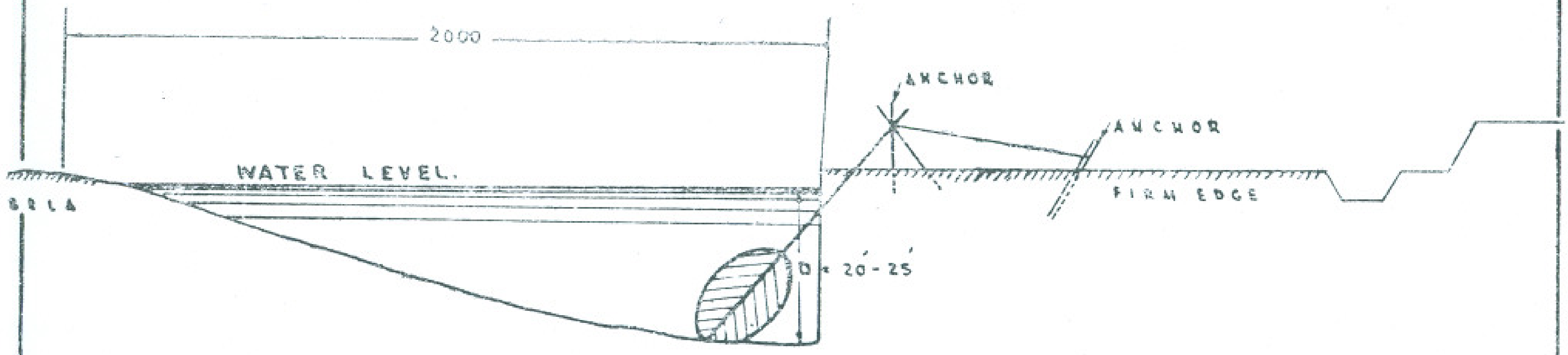


FIG. 2

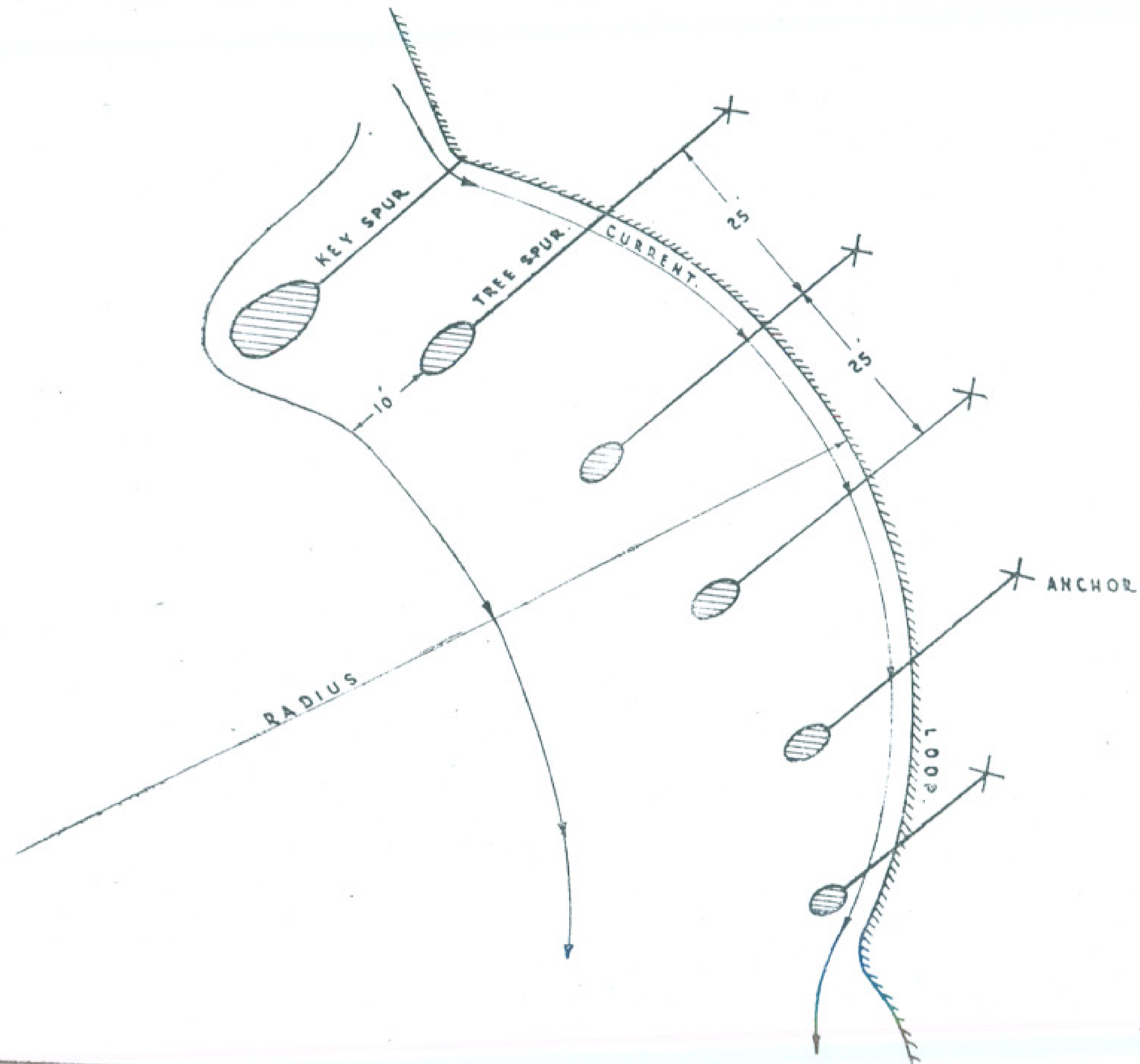


FIG. 3

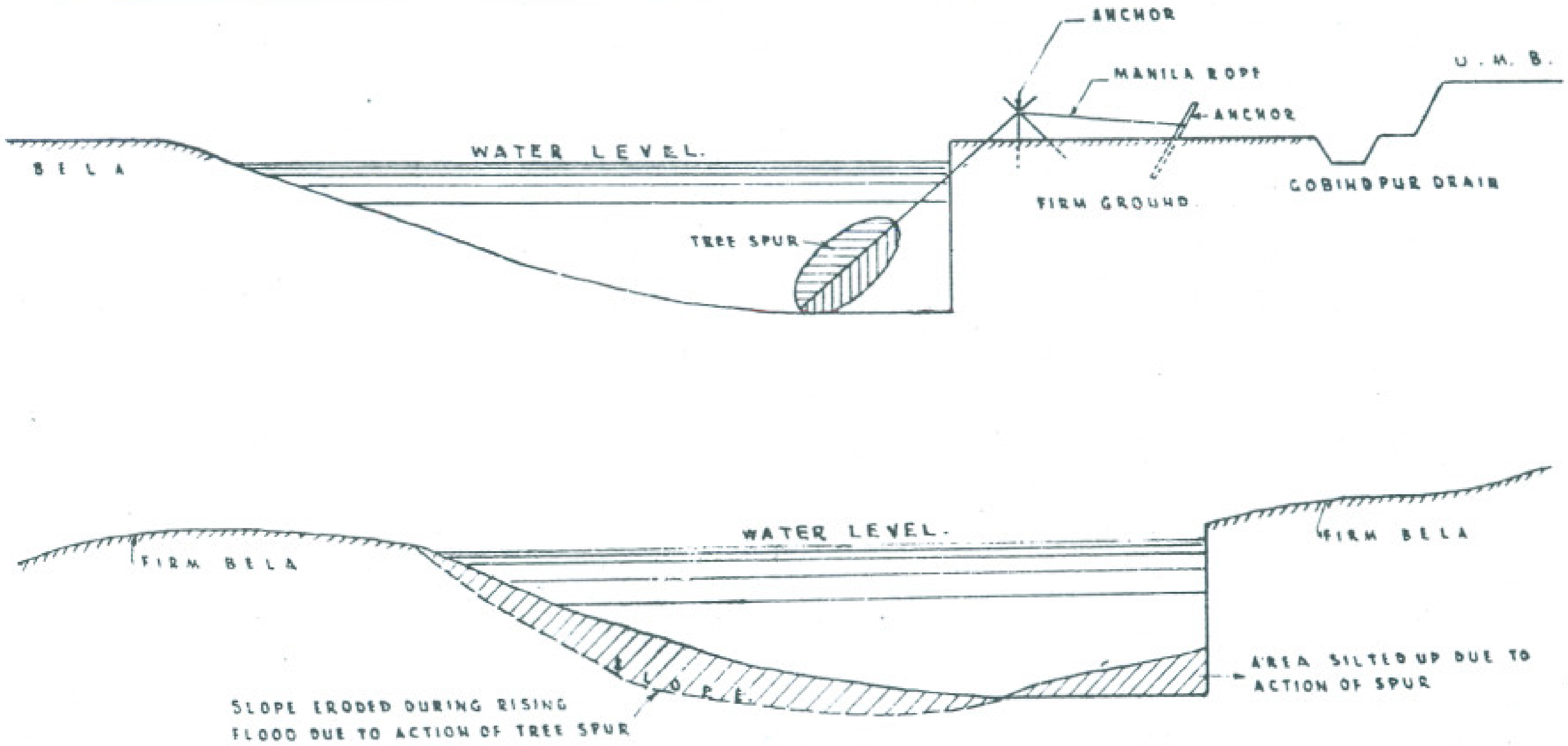
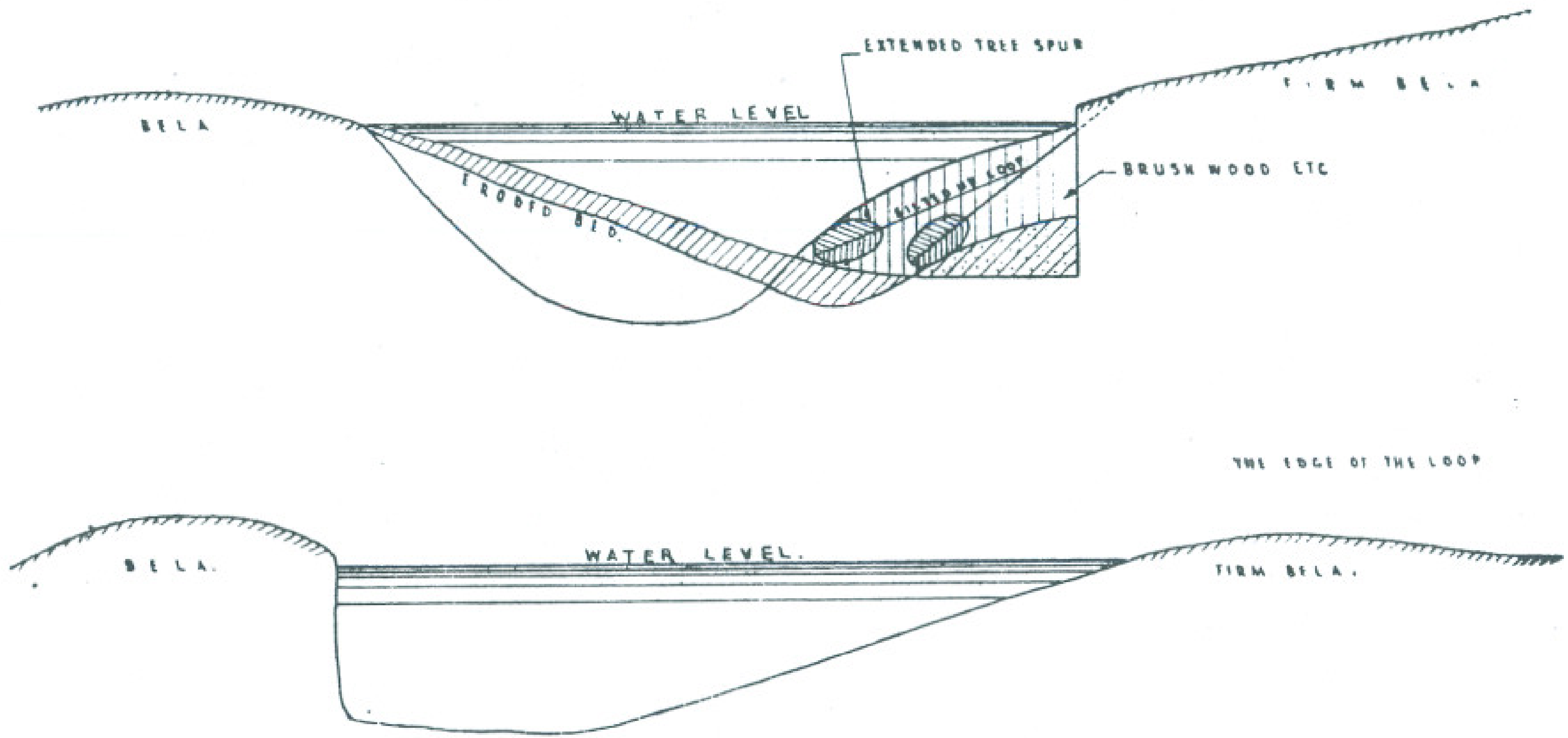
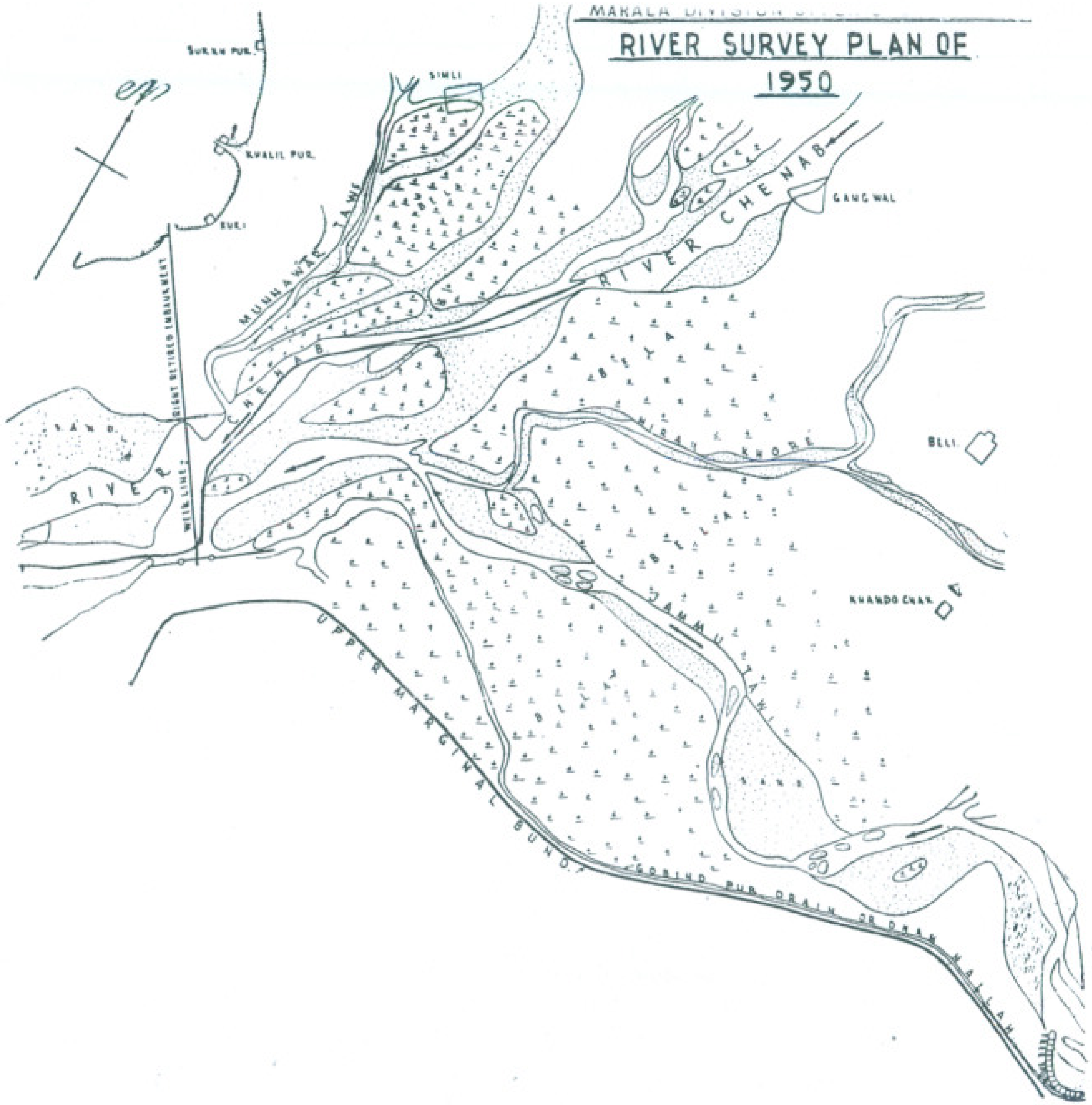

ANCHOR
MANILA ROPE
U. M. B.
ANCHOR
WATER LEVEL.
BELA
FIRM GROUND
GOBINDPUR DRAIN
TREE SPUR
WATER LEVEL.
FIRM BELA
FIRM BELA
SLOPE
SLOPE ERODED DURING RISING
FLOOD DUE TO ACTION OF TREE SPUR
AREA SILTED UP DUE TO
ACTION OF SPUR

FIG 4



REVERSED CONDITION OF STREAM UNDER
THE ACTION OF TREE SPURS

RIVER SURVEY PLAN OF 1950



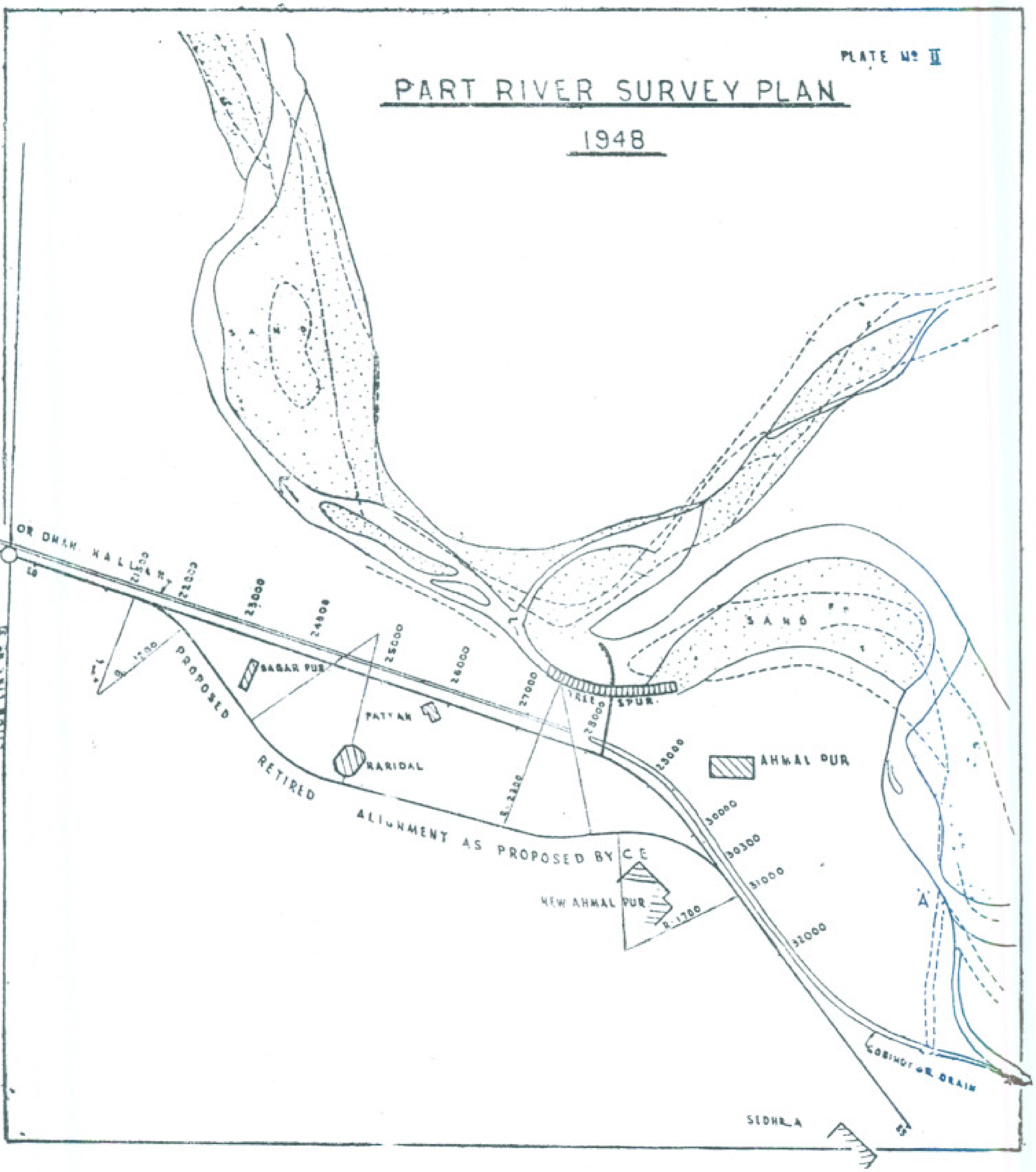


PLATE No II
PART RIVER SURVEY PLAN
1948
SAND
SAND
TREE SPUR
SAGAR PUR
PATTAN
KARIDAL
AHMAL PUR
NEW AHMAL PUR
PROPOSED RETIRED ALIGNMENT AS PROPOSED BY C.E
23000
24000
25000
26000
27000
28000
29000
30000
30300
31000
32000
GOBINDPUR DRAIN
SIDHRA

PLATE No. III

PLAN SHOWING RIVER ACTION

AT R.D. 52000 TO 54535 R. M. BUND

AT PANJNAD H/WORKS

SCALE:- 1/2500

1951

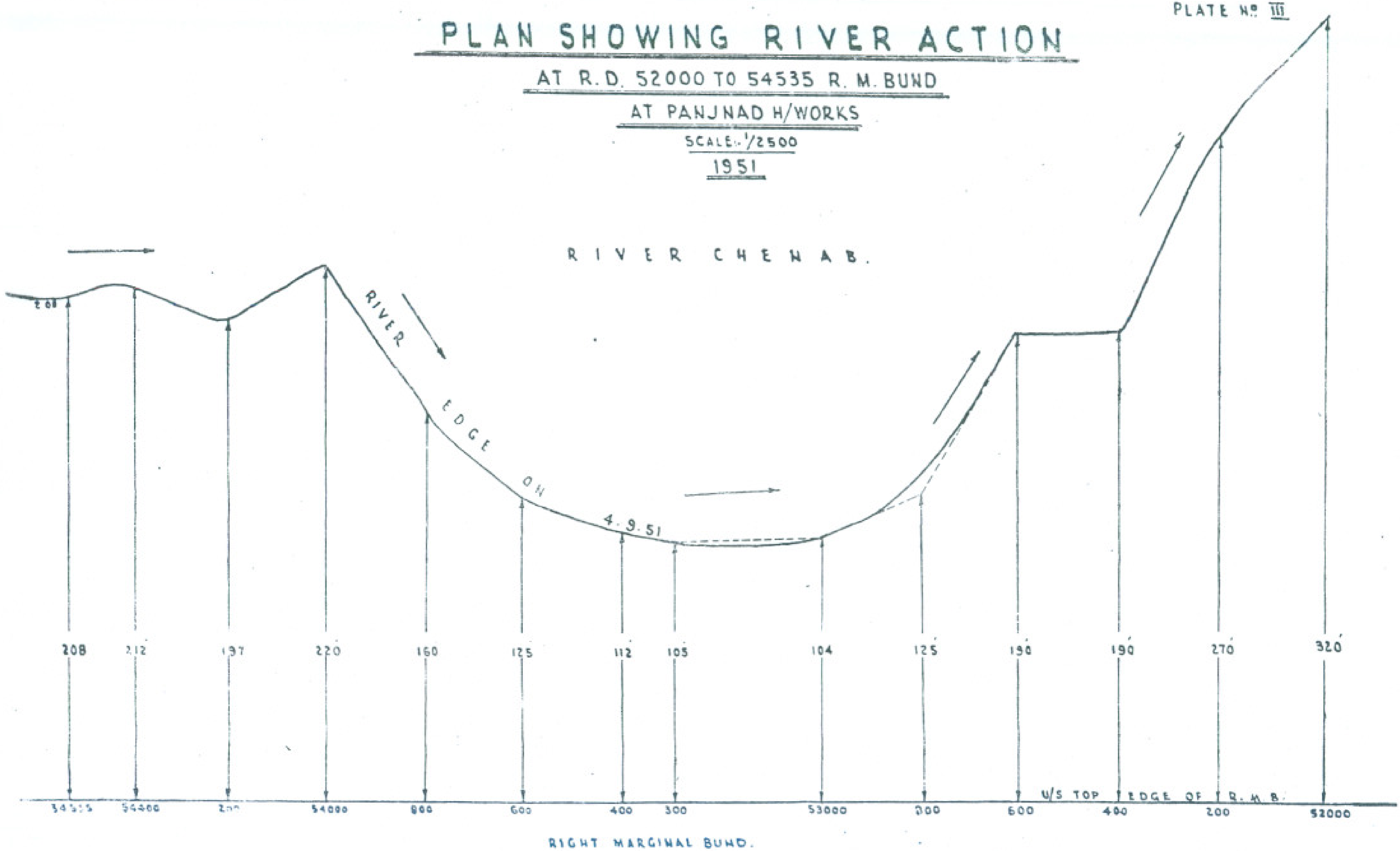
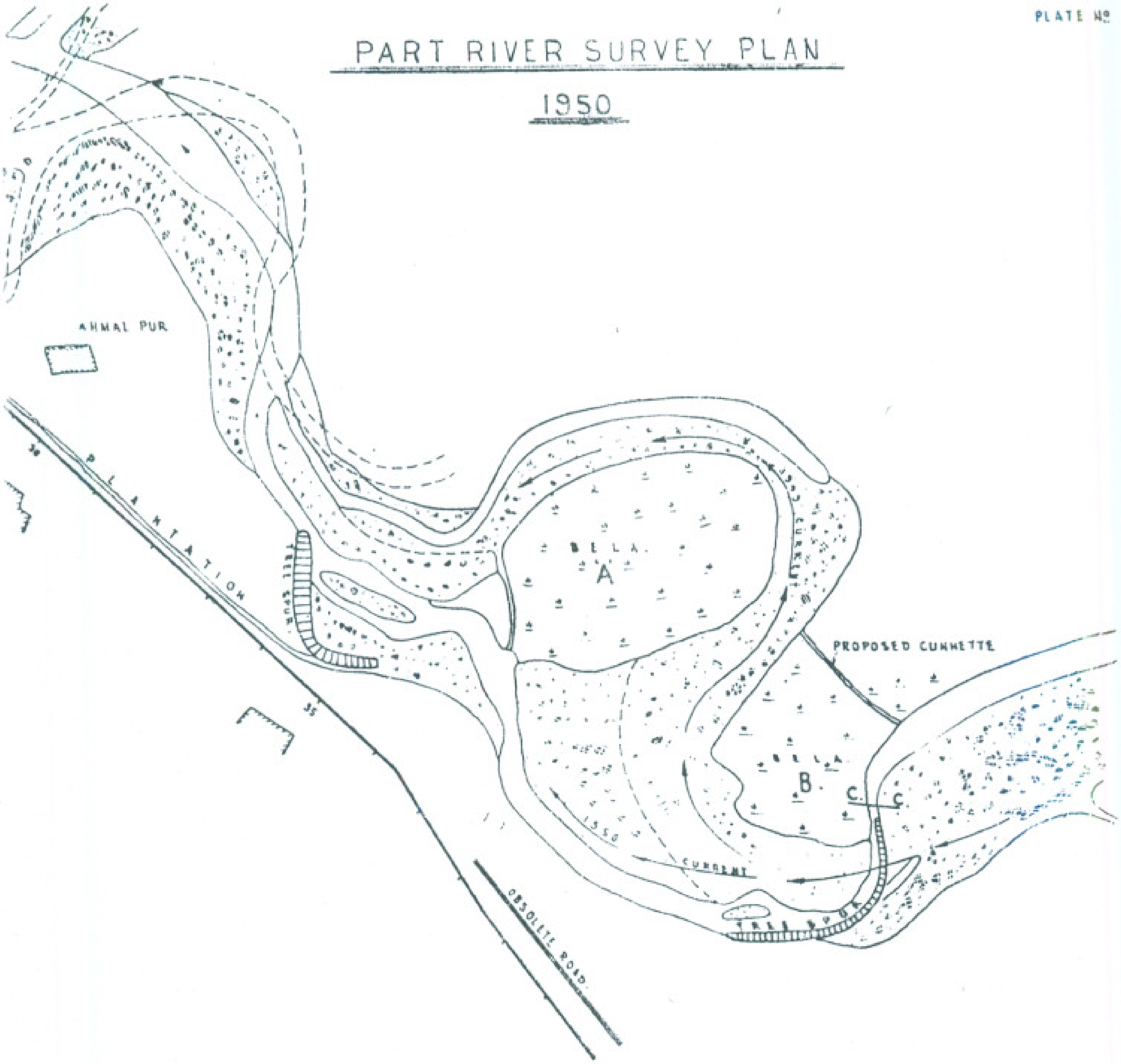


PLATE No. IV

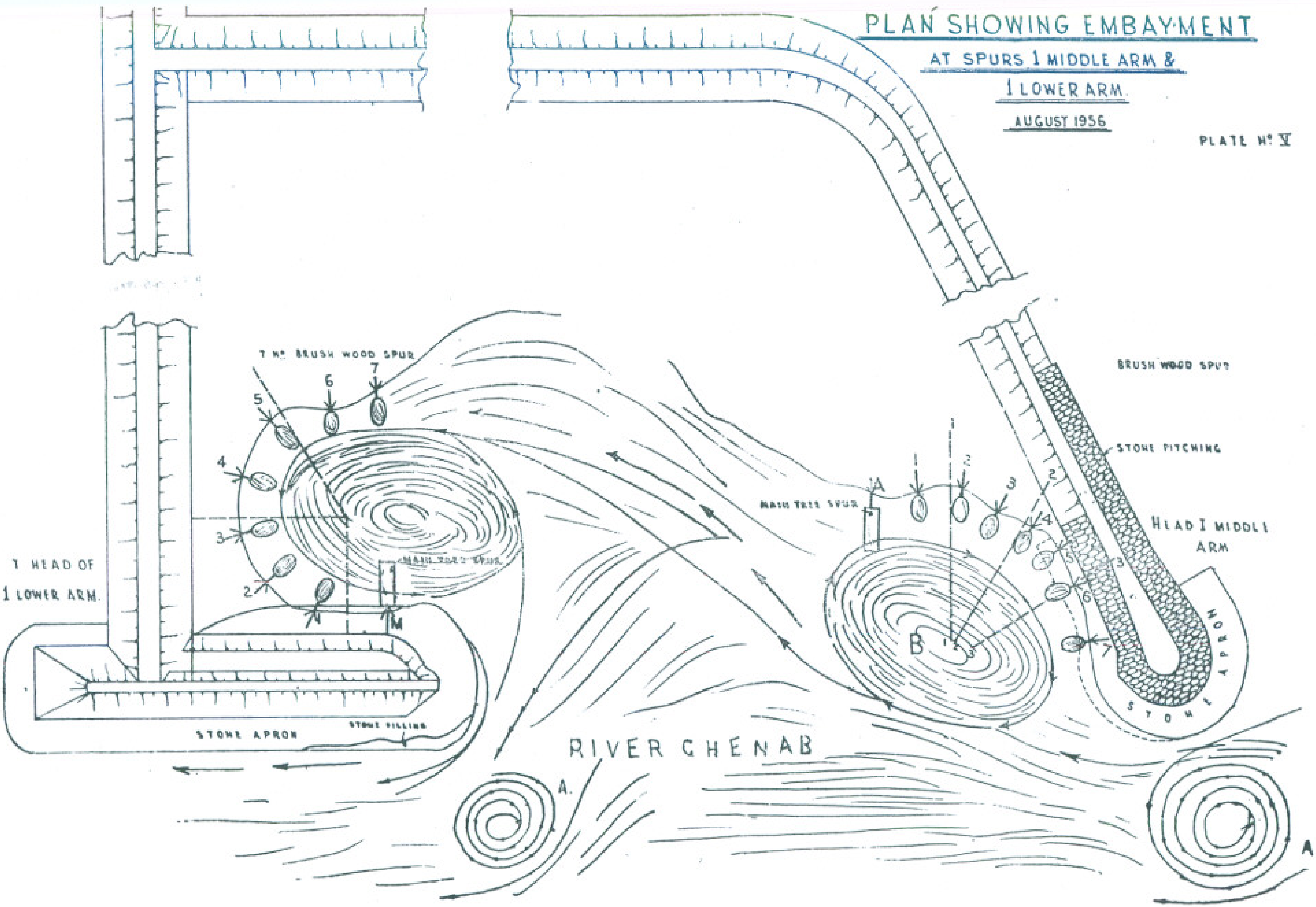
PART RIVER SURVEY PLAN

1950



PLAN SHOWING EMBAYMENT
AT SPURS 1 MIDDLE ARM &
1 LOWER ARM.
AUGUST 1956

PLATE No V



X-SECTIONS OF EMBAYMENT

U/S 1 MIDDLE ARM AUGUST 1956

PLATE No. VI

SCALE: 1/100

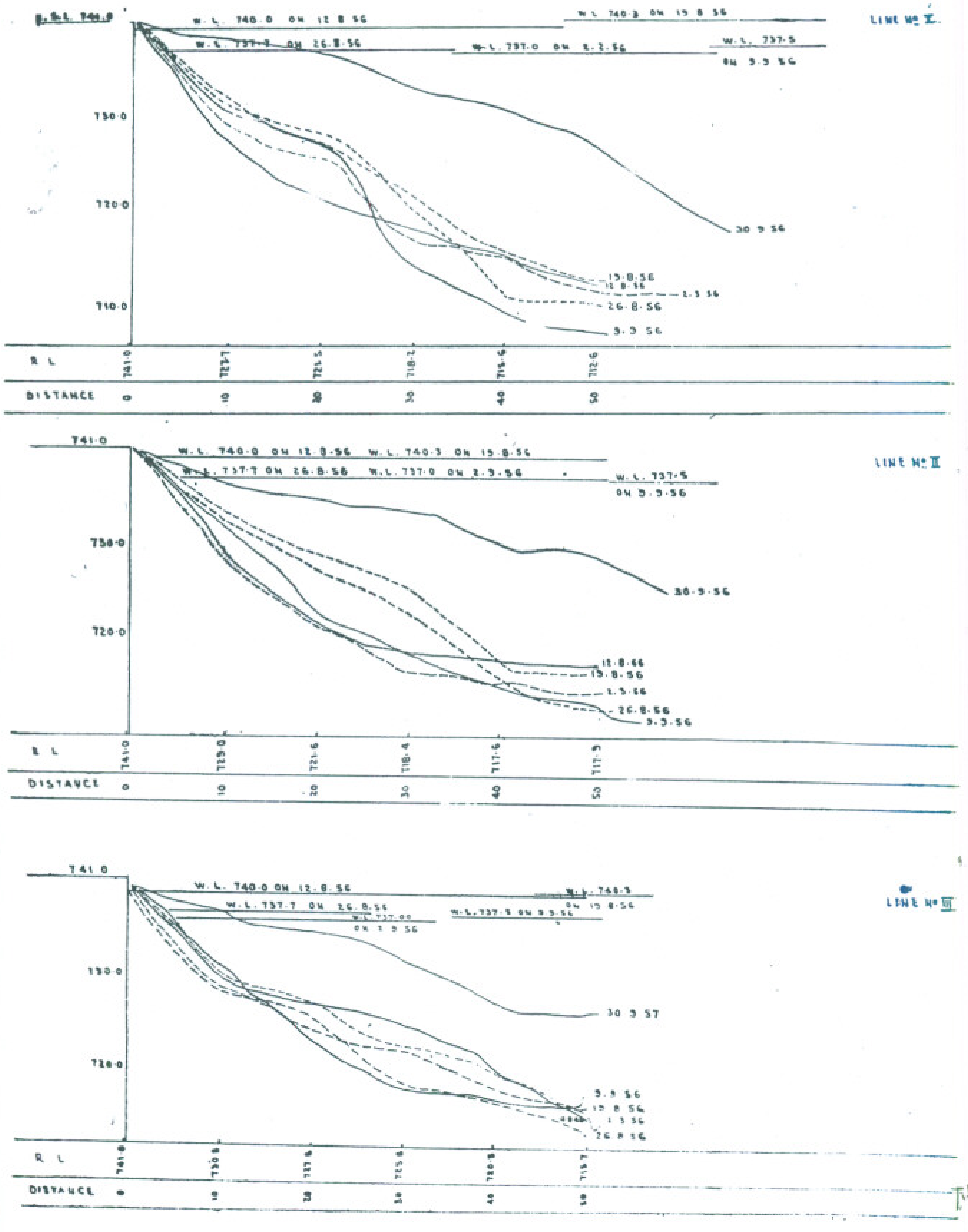


PLATE No. VII

X-SECTIONS OF EMBAYMENT

U/S 1. LOWER ARM AUGUST 1956

SCALE 1/100