PAPER No. 309

River Training Works of Empress Bridge Adamwahan

BY

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INTRODUCTION

The main rail road between Lahore and Karachi crosses the river Sutlej near Adamwahan village on a double line triangulated girder bridge of 8 spans of 250 feet each.

The bridge is known as the Empresss Bridge and is situated between Adamwahan and Bahawalpur railway stations being about 1¾ miles from Bahawalpur and 70 miles downstream of the Pallah Head Works on river Sutlej.

This is the only bridge linking the northern part of the railway system in the West Punjab and North West Frontier province with the southern and western part of the railway system in Bahawalpur state, Baluchistan and Sind and is, therefore, vitally important.

The river at this bridge has been making an active embayment behind the right guide bund for the last four years. The cutting at this bend during 1953 floods was very severe and brought the deepest portion of the bend as near as 800 feet from the railway embankment on the Lahore side approaches of the bridge and thus threatened to outflank this important bridge in the flood season of 1954.

After careful study of the situation the probability of the Right Guide Bund encouraging a cut-off of the embayment on arc-chord ratio principle was ruled out.

This paper deals with the principles, design and execution of the training works which resulted in the river abandoning this deep embayment and taking to a straight course into the bridge.

HISTORY

A brief history of training the river Sutlej at Adamwahan is given in Chapter 4 of Sir Francis J. R. Spring's famous book "River training and control".

The history of the training works will be briefly described in this paper so that the magnitude and the nature of the problem which froms the subject of this paper may be clearly understood.

Injudicious siting of the bridge

The Government of India ordered in November, 1873 to construct the Empress Bridge with 16 spans of 264' (the bridge as constructed was 16

spans of 250') on piers sunk to 100' below low water level. The suggestion of Colonel Peil, the then Chief Engineer, to site the bridge 3¼ miles upstream of the site selected by surveyors because of the permanent bluffs being more defined and close together at the suggested site, was turned down and the bridge was constructed at the site originally selected where the not-so-well-defined permanent bluffs were 3¼ miles apart leaving ample room for the river to meander and make deep embayment. Mr. Spring writes "That the river was liable to such embayments might have been gathered from existing plans of the Sutlej of a few years before, which showed great bend or embayments, 5 miles outside to outside of the bends as measured across the general axis of the river and only 2 miles from bend to bend as measured along the general lie of the axis. Even in 1873 the river was running in a great bend, for a distance of 1½ miles parallel to, and only half a mile above, the bridge line".

Training works as constructed with the bridge

The Empress Bridge was provided with training works as shown in Plate No. 1 at the end of seventees and consisted of the following works These were not an example of the guide bund system, yet they had the semblance of that system.

(*a*) The right bund about 5500 ft. long consisted of an embankment JA splaying from the abutment at about 60 degrees and terminating at the eminence on which the village of Adamwahan stands. The bund was faced on the river side with 13" burnt clay cubes. The protection ended in a vertical drop over 9 blocks deep. No apron was provided. The right bank exists even to-day mostly as it was constructed and is now known as the Right marginal bund.

(*b*) The main left bund ran along the alignment MGH for about 2½ miles and terminated at the high river bank H. The proctection was similar to that provided on the right guide bund. The left bund was also provided with pitching stone and apron in 1898.

Shortening of the bridge to half its length and construction of Bell's Guide Bunds

The river after crossing the Railway line near Adamwahan used to run more or less parallel to the Railway line upto Samasata,an important junction station about 6 miles downstream. To protect the Railway line in this length, series of bunds and spurs were constructed. These protection works covered the main line from M. 513 to 511. Though these spurs were constructed to protect the main line embankment by keeping away the river, they actually had the opposite effect and attracted and held the river when it was trying to break away during 1918 to 1923. In 1924 and 25 it broke away only to be re-attracted by them in 1926-29 as illustrated in plate No. 6. The meandering tendencies of the river continued to give trouble for well over 50 years and proved that these meanderings were mainly due to the excessive water way provided by the bridge whose length was twice that which accumulated experience of years could sanction. It was, therefore, decided in 1913 to halve the bridge and this work was taken in hand only in

1926 when proposed introduction of heavier axle loads necessitated the reconstruction of the bridge, and the increasing traffic which was throttled by the bottle neck over the single line bridge, made it necessary to double the track on the bridge. The bridge was halved and 8 spans of 250′ were provided with double line track and opened to traffic in November, 1930. The river, for many years had flowed through the left spans of the bridge and so the right half of the original bridge was closed and a new right guide bund was constructed with its length equal to the length of the new bridge and provided with pitching stones on the slopes and 60′ wide apron on straight and 80′ wide apron round the mole head. This guide bund BK still exists in this shape.

The left guide bund was strengthened and provided with a tail in the same year when the right guide bund was constructed and it was made symmetrical to the right guide bund. This bund CD also exists to-day in the same shape as it was constructed.

Meanderings of the river after shortening of the bridge

The shortening of the bridge and provision of guide bunds disturbed the regime of the river which started meandering in its 'khadir.' In 1931 the river cut into within 600 ft. of the main line opposite mile 511⅓ but it suddenly changed its course and remained well away upto 1932, In 1933, however, it again changed its course and started cutting towards the line opposite mile 110½ and it came within 540′ of the Railway line. The line from Mile 511⅓ to 507 was endangered due to this change in the course of the river and track in this length was realigned during 1934. The river cut this 540′ length in the following floods of 1934 and breached the Railway embankment. Had timely action not been taken to realign the main line and shift further back out of the area of oscillations of the river in 1934 the vital rail link between Lahore and Karachi would have been breached.

By 1934 the channel had broken away from the protection bunds and spurs mentioned above, but a deep meander developed towards Samasata from 1934 to 1943 The two loops made by the meander mentioned above continued increasing by erosion. In 1942 the spill water from the river flooded the Samasata yard causing considerable damage. During 1942-1943 the erosion of the river towards Samasta was rapid and heavy and the sharp loop of the river was within a mile of the yard. As there was a potential danger to the station yard due to rapid erosion of the left bank, Mr. Inglis, Director of Indian Water-way Experimental station Poona was consulted in 1943 in regard to protection works and training of the river near Samasata. On his advice a repelling groyne was constructed before 1945 flood season. In the rising flood of that year this groyne acted satisfactorily but in the falling floods a clay bluff on the left bank about 800′ upstream of the groyne, eroded and completely changed the direction of flow. Owing to the direct attack by a strong current the groyne gave way on the point it was not sufficiently armoured. After further consultations the original spur was repaired and strengthened.

In 1946 floods the spur again failed due to a portion of the spur 200′ long, not fully protected, giving way. After this failure the isolated groyne

also caused heavy accretion below it while further erosion of the left bank continued and so did the increase in the arc/chord ratio. This ratio had reached as high a figure as 2.8 in 1946, yet no cut off took place.

During this period, consultations both with the Indian Experimental station at Poona and the Punjab Irrigation Department continued. The former recommended the construction of a very heavily armoured groyne but as there was no time to construct it, their alternative suggestion of a permeable leafy groyne was adopted.

During 1947 floods this leafy groyne did act in the beginning although with every flood some of the rail piles gave way and by the end of the Monsoon the middle portion of the leafy groyne had collapsed. By September, 1947 when last heavy flood occured the arc/chord ratio of the loop near Samasata had reached 2.8 and a cut off started through an auxiliary nala known as the Sharabi nala.

In the floods of 1948 pilot cuts connecting the river bed with the large scour holes in the Sharabi nala were made and they assisted in establishing a cut off along the Sharabi nala. The cut off occurred rapidly and completely along the Sharabi nala and the threat to railway line from the embayment was averted.

The river established a deep embayment 20 miles upstream of the bridge near mile 31 on Samasata-Bahawalnagar branch line and came very near to the Railway line. Realignment of the railway line was done in 1950 and an embankment was constructed to divert the Rly. line in case the river came too close to the track but fortunately the river established a cut off and this diversion was not needed.

Eversince the construction of the right guide bund the main current of the river has been touching the mole head of this new guide bund and has been making an embayment behind its mole head. The river stream continued to cut at this point year after year and these erosions became more severe after the establishment of the Sharabi nala cut off in 1948.

Efforts to train the river in 1952 & 1953.

The cutting of the bank at this bend was frought with the danger of outflanking of the Lahore side approaches of the bridge and specially because of the easily erodable soil at this place which had been the bed of the river before the closing of the right half of the bridge. Three permeable spurs of sand bags and pilchi mattresses kept in position by bullies driven all round, were constructed in 1952 at a distance of one mile up stream of the bridge as shown in plate No. 1, to divert the main stream of the river away from the right bank but these spurs could not stand and were quickly washed away by the high flood in 1952 without bringing about any change in the course of the river.

Three permeable spurs longer in length and of the same design were again constructed on the right bank at a distance of 3 miles up stream of the bridge in 1953 as shown in Plate No. 1. The presence of these spurs disturbed the regime of the river which started cutting its right bank upstream of these spurs. The river crowded down upon the spurs and washed them away

in September, 1953 but before it could do so it had cut a distance of more than 900′ on a deep bend behind the point of location of these spurs and had diverted the main stream of the river from the right bank to the left bank as shown in plate No. 1. After striking the left bank on the hard clay point 'P' the river stream was deflected again, to the right bank at the point Q on the bend near right guide bund mole head where it caused heavy cutting. The main stream after hitting the point Q was thrown on to the right guide bund at point R where active cutting started.

At the end of 1953 flood season, when all erosion stopped, the minimum distance of the toe of the main line embankment from the bend near the right guide bund was only 800 ft.—a length which could easily be eroded by the river in one flood season.

THE PROBLEM

The previous history of the bridge shows that the river is capable of eroding more than 800′ of its banks during one flood season. In 1933 when the river threatened the main line embankment between Bahawalpur and Samasata, it cut a length of 840′ of its banks in the flood season of 1933. Again in the year 1953 the river cut about 900 ft. of its bank upstream of the point where the three permeable spurs had been located. After the floods of 1953 had subsided the minimum of distance of the toe of the main line embankment from the river embayment near the right guide bund was only 800′. The situation was, therefore, alarming and called for immediate measures for stopping further embayment of the river at this point to avert the threatened out flanking of the bridge and its approaches. The main stream in 1953 also attacked the right guide bund along half of its length from the mole head. This guide bund is not provided with apron on its back and therefore an attack of the river at the back of the bund was full of dangerous possibilities. The possible outflanking of the right guide bund would have resulted in the outflanking of the bridge. It was, therefore, necessary to counteract this danger.

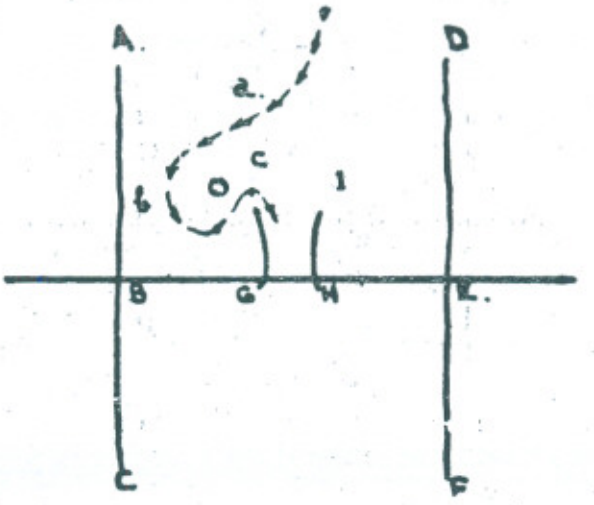


FIG: (i)

ABC & DEF indicate the flood banks of a river within which it is free to meander. A railway line crosses at BE, and the normal flood width BE is curtailed to GH where a bridge is constructed, the lengths BG & HE being merely the permanent way on earthen banks, as also are the two Bell's bunds GO & HI built of earth and running upstream for a short length. These are the Bell's bunds which form still water pockets on either side, by which the river is held in complete control.

The noses and faces of the bunds exposed to active flow are pitched heavily with loose stone, a wide apron of which also extends out over the river bed. The stone in the apron, as it becomes under scoured drops lower and lower until the face is effectively paved to the lowest scour. Beyond this no other stone protection is needed as water in the still water pockets creates pressure only.

The efficiency of these pockets, therefore, depends entirely upon the stoppage of all flow. For this they must be deep enough to neutralize the swirling attack which may take place when the river swings upstream of the bridge against either bank. One such attack on the right bank is indicated in fig. 1 at abc by the arrow heads. The swirl created within the pocket must not reach within dangerous limits to the permanent way embankment which, being unprotected, could not withstand scour. This might happen if bunds are too short.

The still water pocket is not only the secret of safety, but it has also the power of correcting the deflected flow as shown by abc. Being tied up, afflux results and the loop becomes more and more doubled back upon itself, in which process while the loop abc lengthens, the chord ac remains the same, or may grow shorter. Floods overtop the intervening shoal and acquiring greater velocity along ac, set up retrogression of levels which in time completes a short circuit (or cut off) ca. Moreover the still water pocket, by creating afflux, reacts on the river for some distance upstream, which raises the head at a, and in doing so assists the short circuiting action by increasing the velocity along ac.

It is the principal function of the heads of guide bunds to induce cut offs and by this means to bring back between the guide bunds the river which would otherwise have breached the approach banks and outflanked the bridge.

In rivers, we often find, almost side by side, the active river carrying all the flood water running in long easy curves, the dead or dying river in curves

of increasing sinousity. From these characteristics two forms of cut-offs appear to arise as illustrated below :—

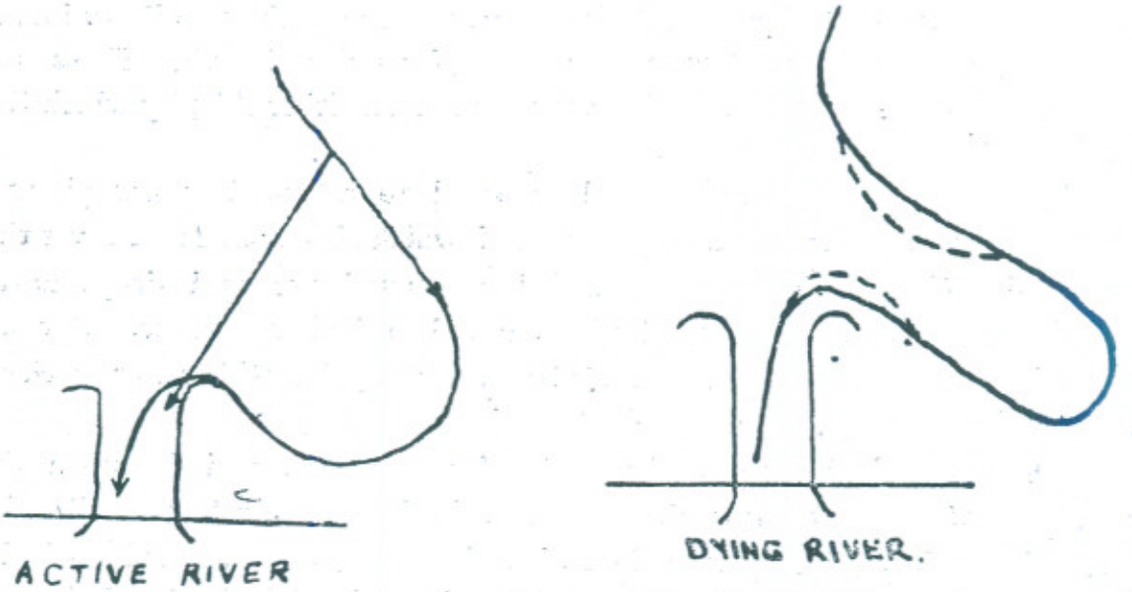


FIG. 2

The active river embaying at the back of the guide bund will cut off at a low ratio of bend to chord because flood waters will submerge the sand bank found on the concave side of the bend and by taking the short course along the chord will form a channel before the growth of grass and bushes makes it too difficult.

The dying river, on the other hand, will increase its curvature by eroding the concave curves and if floods no longer submerge the intervening sand bund, the curvature will continue to increase until either the velocity of the stream is so reduced that banks cease to be eroded, or until the loops cut into one another and a cut off occurs by bend erosion. Such cases are, however, few and less important. Cut offs in active river play a dominating part in training works.

Sir Robert Gales, the Engineer who designed and constructed the famous Hardinge Bridge and its training works on the Lower Ganges at Paksey (East Pakistan), has observed in his paper on "River Training Works" published in one of the issues of the journal of Institute of Civil Engineers that——

"It is reasonable to suppose, and it appears to be borne out by observation that the serpentine course of an active river running in sand between fixed banks would travel continuously (though slowly) down country, without the occurrence of any cut offs but that if this movement were checked at any point by natural features such as kankar or clay beds found in the alluvium, the bend of the river will crowd down upon the obstruction until the ratio of length of bend to length of chord had increased to such a degree that in one

or more flood seasons a cut off channel would be established on the line of the chord.

When an alluvial river has been bridged and provided with flanking guide banks, the head of one or other of the guide bank has the same effect on the regime of the river as has been attributed to natural features, and the resulting cut off brings the river back to the bridge on a more direct course.

It would be seen that every alluvial river has its own particular ratio of length of bend to length of chord at which it may be expected to cut off and that the ratio would vary according to the characteristics of the river at the site of the bridge, such as the magnitude of the river, height of flood rise, surface fall, material of bed and its suitability for growth of protective grasses and bushes etc. etc".

For lower Ganges Sir Robert Gales gives this cut off ratio as 1. 75.

Factors determining the design.

Sir Francis Spring has laid down that the upstream length of guide bunds depends largely (*i*) on the breadth of the untrained river and (*ii*) on the radius of its worst bend. He says that the radius of the worst bend is more or less ascertainable for any given stretch (of 50 miles or so) of a particular river. The radius of the worst curve depends on many factors such as relationship of velocity to coarseness or fineness of bed sand rise and duration of floods etc. etc. but these are more or less the same factors apart from natural undulations of the main surface of the country on which the breadth of the bottom or 'khadir' of such rivers is dependent. Each stretch of river has a more or less discoverable worst, that is smallest radius of bend to which its main channel may twist before it sees fit to short cut and straighten itself.

He also says that the limits of the flood banks of a river between which it is free to meander should be ascertained and due attention should be paid to the possibility of the river bending round either guide banks into the still water area at the back of the bund and eroding the main approach bank. In specially wide khadirs this may involve the use of very long guide bunds. Figure No. 3 taken from Sir Francis Spring's book shows the effect of a short Bell's bund and fig. 4 shows how the danger can be avoided by providing longer guide bunds.

For rivers having a flood discharge ranging from 2, 50,000 to 7, 50,000 cusecs according to Sir Robert Gales the upstream length of guide bunds is kept equal to the length of the bridge, but a longer length may be required to protect the aprroaches of the bridge in case of a very wide khadir.

Figures 5 (a), (b) and (c) have been reproduced from Robert Gales' paper to illustrate the effect of the three factors, width of khadir, the radius of worst bend and the cut off ratio on the design of the upstream length of guide bunds.

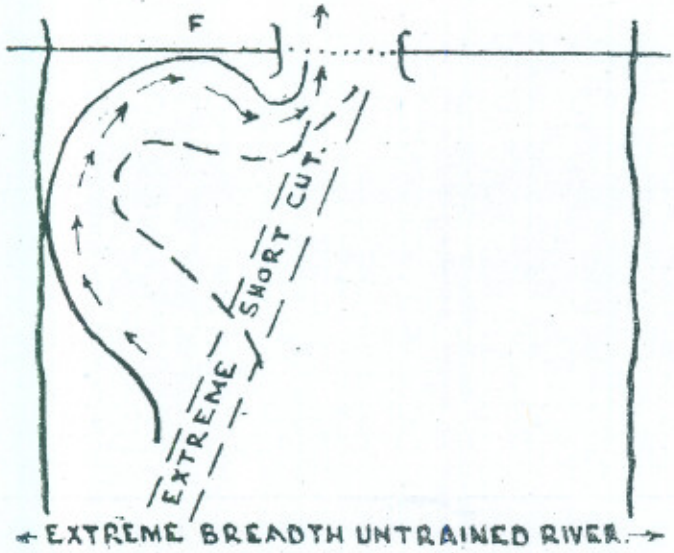


FIG: 3

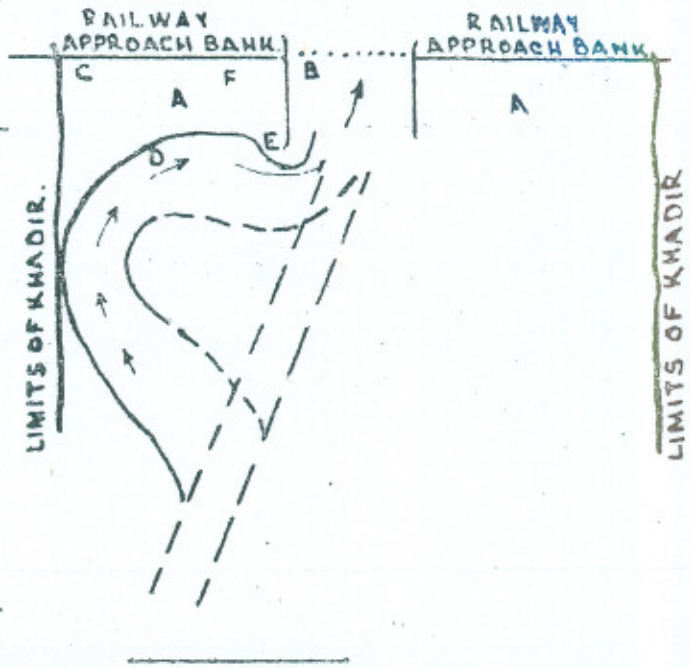


FIG: 4

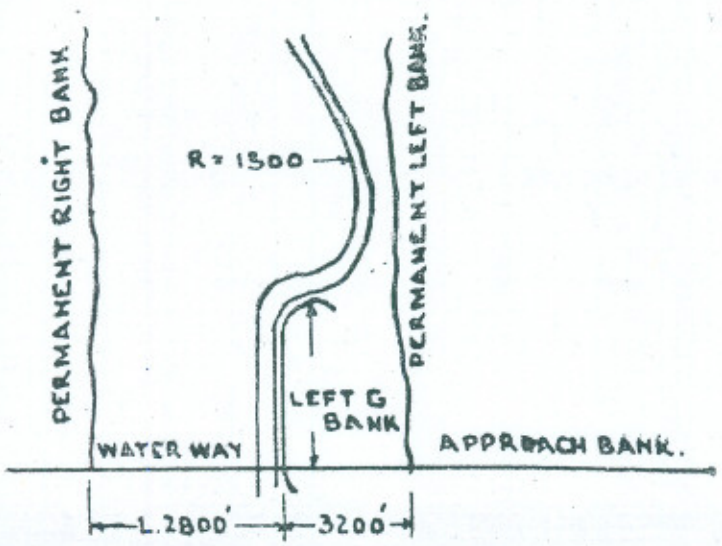


FIG 5 (a)

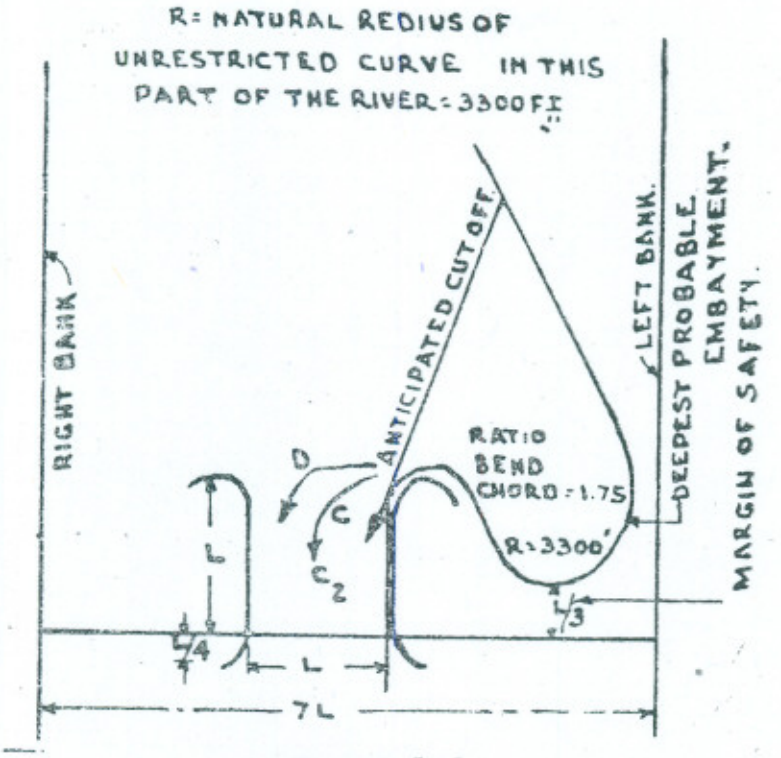

R= NATURAL REDIUS OF
UNRESTRICTED CURVE IN THIS
PART OF THE RIVER = 3300 FT
RIGHT BANK
ANTICIPATED CUT OFF
LEFT BANK.
DEEPEST PROBABLE
EMBAYMENT.
MARGIN OF SAFETY
RATIO
BEND
CHORD = 1.75
R=3300'
D
C
C2
L
L/4
L/3
L
7L

FIG 5 (b)

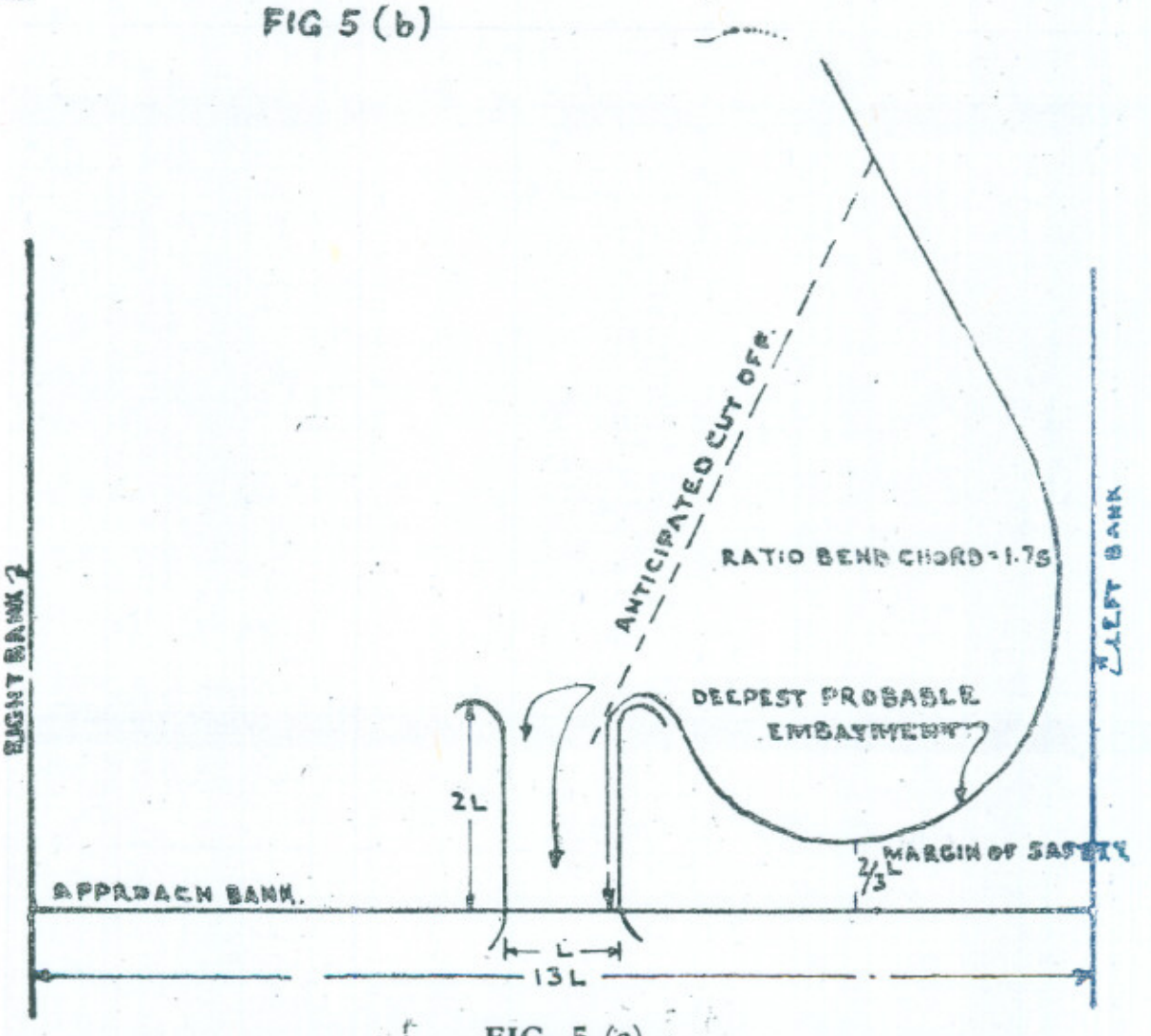

RIGHT BANK
ANTICIPATED CUT OFF
RATIO BEND CHORD = 1.75
LEFT BANK
DEEPEST PROBABLE
EMBAYMENT
2L
2/3 L MARGIN OF SAFETY
APPROACH BANK.
L
13L

FIG. 5 (c)

A DISCUSSION ON THE ADEQUACY OR OTHERWISE OF THE GUIDE BUND SYSTEM AT EMPRESS BRIDGE, ADAMWAHAN.

Width of khadir and limits of flood banks.

The river Sutlej at Empress Brirge has a wide khadir and no permanent bank or bluffs and the oscillations of the river on the right bank are not controlled within any well-defined limits. The river has not yet touched the right marginal bund. It is very doubtful if this right marginal bund which is not equipped with proper aprons will be able to withstand the scouring action of the river below low water level. If this bnnd is not successful in checking the meanderings of the river the danger of the bund eroding aw ıy the railway approach bank and outflanking the bridge will increase manifold.

Worst bend and cut off ratio.

Survey plans of the river upstream and down-stream for serveral miles were studied to find out the radius of the " worst bend ". It is found that the river is capable of taking a sharp bend of 800 ft. radius before establishing a cut off.

The river in 1915 took a sharp bend of 800 ft. radius between two strong clay points and then established a cut off in 1916 when the ratio of arc/chord became 2.1 as is shown on plate No. 6.

In 1948, the river took a bend of radius 5100 ft. and then established cut off along the Sharabi nala when the ratio of arc/chord was 2. 8.

The river was flowing in a deep bend 20 miles downstream of the bridge in 1950 when it established a cut off at 5,400 ft. radius and a cut off ratio of arc/chord of 2. 5.

The radius of the worst bend for the river in the vicinity of the bridge should, therefore, be taken equal to 800 ft. and it may be expected that a cut off will be established when the arc/chord ratio is of some value between 2. 1 to 2. 8.

The upstream length of the right guide bund is only equal to the bridge *i. e.* 2000 ft. and is, therefore, quite inadequate to ward off the dangers of a deep embayment behind its head by establishing a cut off and specially so because the river at this place has a wide khadir with no permanent bluffs and the main stream is capable of taking a bend of as narrrow a radius as 800 ft. which would only cut off when the ratio of the length of the loop over the chord of the bend becomes as much as 2.1 to 2. 8.

In plate No. 6 the "worst bend" of 1915 has been reproduced between the right guide bund and the right marginal bund to illustrate the possibility of such an embayment outflanking the approaches of the bridge. This embayment in 1915 was between two hard clay points. In the illustration at the bridge site the head of the right guide bund and the right marginal bund has been taken as the two strong points restricting the embayment which if placed in this position would cause a breach of the bridge approaches.

Increasing the length of the right guide bund would not solve the problem as the oscillations of the river have no limits on the right bank and the embayment threatening the bridge approaches would not thus be satisfactorily checked.

PROPOSALS FOR TRAINING THE RIVER

It was decided to take steps——

(a) To check further erosion at this bend behind the right guide bund, and

(b) provide means to coax the river to take to a straight course into the bridge.

To check further erosion at the embayment.

It was first proposed to construct a ring bund starting from chainage 1500 of the Right guide bund running all along the bend and terminating at the Right marginal bund as shown in plate No. 2. This ring bund was to be provided with launching stone apron all along its length to counteract further cutting of the banks at this embayment. It was also proposed to provide four chain lengths of stone apron to Right marginal bund also so that if the river scoured the hard clay point in front of the marginal bund, it may not cause a breach of this bund. The estimated quantity of earth work and the pitching stone required was 22 lacs cft. and 20 lacs cft. respectively and the cost of the whole work was estimated as Rs. 5,80,000.

This proposal was dropped as it was too costly and it was decided to construct a mole head spur as shown on Plate No. 3. This spur was to be sited in such a way that the two bends, one between the Right guide bund and the mole head spur and the other between the mole head spur and the right marginal bund, when drawn with the 'worst curve' radius of 800 ft. did not go further toward the bridge approach banks ensuring an early cut off.

The estimated quantity of earthwork and pitching stone for the mole head was 1,50,000 cft. and 1,30,000 cft. respectively and the work was estimated to cost Rs. 42,570/-.

To straighten the course of the river.

It was proposed to dig a pilot channel in the river bed upstream of the bridge to encourage the river to take to a straight course into the bridge.

Two alignments were surveyed and proposed as shown in plate No. 2.

Alignment 'A'.

It was proposed to dig a channel 5560 ft. long as shown at PX. The main stream of the river, having been diverted from the right bank to the left, was hitting the hard clay point at P in the floods of 1953.

It was, therefore, hoped that if the mouth of the pilot channel be sited at P and the hard clay patches be dug out the river will quickly erode its

course along the channel PX straight to the bridge. The cut off ratio of bend/chord for this channel was measured as 2. 4. which was a favourable ratio for the establishment of a cut off.

The estimated cost of this channel was Rs. 32,000/-.

Alignment 'B'.

It was proposed to dig a pilot channel of 4050 ft. length as shown at RS on plate No 2. The main stream of the river in the floods of 1953 was flowing parallel to the left bank at the point S, which was to be the off-take of the proposed pilot channel RS. It was, therefore, proposed to construct a permeable spur 200 ft. long at the point T as shown in the same plate to deflect the main stream of the river on to the inlet of the pilot channel. The permeable spur would, of course, have been washed away in high floods, but it was hoped that by the time this occurred, the main stream would have carved out for itself a smooth entry into the channel.

The cut off ratio for this channel as measured was 2. 28.

The channel was estimated to cost Rs. 18,000 and the permeable spur Rs. 14,000/-, the total cost being Rs. 32,000/-.

The soil along alignment 'B' was mostly sandy with a few patches of clay here and there and thus stood better chances of erosion than the alignment A which was longer and costlier. It was, therefore, decided to dig the pilot channel along the alignment B and not to construct the permeable spur.

It was also decided to request the Director Irrigation Research Institute to construct a model of the Empress Bridge in their laboratories to test the efficiency of the proposed training works.

RESULTS OF EXPERIMENTS ON THE MODEL

A model of Empress Bridge with a proto type river for two miles upstream and one mile downstream was constructed in the Irrigation Research Institute at Lahore and the behaviour of the proposed pilot channel and the mole head spur was studied carefuliy.

The channel was reported to have opened and developed for some time and then to have silted up again, the river having taken to its old course.

The Director Irrigation Research Institute, therefore, got an earthen bund constructed on the model, downstream of the mouth of the channel. He, then, reported that the channel started functioning at a discharge of 10,000 cusecs and that if a sand bund be constructed about 200 ft. downstream of the mouth of the channel to assist the development of the channel, it will be rapidly developed in about ten days time. The bund was to be designed to with-stand a discharge of about 45,000 cusecs.

Orders were issued for the construction of a sand bund about 200 feet downstream of the mouth of the pilot channel, with the top of the bund at RL 375.0 and its upstream and downstream slopes as 1 in 5.

CONSTRUCTION OF THE NEW TRAINING WORKS.

The pilot channel.

The digging of the pilot channel was commenced on 4. 2. 54 and the work was completed on 7. 3. 54. All hard clay patches in the bed of the channel were dug out and splayed bell mouth entry and exits were provided at its ends. The bed of the channel was given a slope of 0.2 ft./1000 ft. The quantity of earth work done was 882,746 CFT. and the total work cost Rs. 15,200/-.

The sand bund.

The sand bund is a misnomer. It was not intended to build the bund entirely of sand but to build it with the material readily available near the site of the bund, in the bed of the river which is sandy,

The bund was required to be a compact mass offering great resistance to percolation of water and to settle evenly without cracks or cavities forming on excessive drying *i e.*, it was to possess the qualities of water tightness and shear resistance. The characteristics of a good soil for bund building are compaction *i.e.*, cohesion and irregularity of individual particles and high specific gravity. The desirable soils are, therefore, mixtures rather than individual grades. Sand provides shear resistance by friction while clay provides cohesion and water tightness. The best mixture is that in which the pore space in the coarser sand is completely filled with the finer grain of sand silt and clay. The soil most nearly meeting these requirements is sand mixed with a fair proportion (30 to 40%) of clay. Pure clay shrinks and cracks when it is dry and pure sand is not water tight. The sand mixed in the clay prevents shrinkage and cracks without destroying the water tightness and toughness of the clay.

It was, therefore, decided to build the bund with sandy clay available in the river bed near the site of the bund.

The bund had to be designed so that the water that percolated through it, as it must due to the bunds not being absolutely water tight, had the surface of the percolating water (the line of saturation) well within the downstream toe and had sufficient cover of earth (about 4 ft. height of earth) everywhere over it.

The saturation gradient depends mainly on the poresity or permeability of the soil of which the bund is made and to a much lower extent on the permeability of the soil on which it is built. If both materials are alike, as in this case in river Sutlej, the position of the saturation line will always be same regardless of the permeability. The more porous or permeable the material the flatter the saturation gradient. Thus pure coarse sand has a saturation gradient of the order of 1 in 10 to 1 in 12, while impervious clay has a gradient of about 1 in 4.

The saturation line for bund constructed of sand mixed with 30 to 40% clay was taken as 1 in 6.

The top of the proposed bund was kept at RL 375.0, which would make the bund 13 feet high in the deepest portion. A uniform top width of 10 feet was kept throughout the length of the bund. The rear slopes of the bund were kept as 1 in 5 to keep the saturation line of 1 in 6 well within the downstream slope. In the deep portion a berm 4 feet high was constructed at the toe to give adequate cover over the 1 in 6 saturation gradient. Two rows of sand bags and pilchi mattress tied to wooden pegs were provided to protect the river slope from erosion in the deep portion.

The upstream slope has generally to be flatter than the under water angle of repose of the material, which is flatter than the angle of repose of the same material in the air. The slope of bunds is generally kept 2 : 1 to 3 : 1 but where wave wash is considerable the upstream slope is flattened to 4 : 1 to 5 : 1.

In this case the upstream slope was also constructed as 5: 1.

The sand having little cohesion, the sand bunds are quickly washed away by wave wash. The upstream slope of the bund was therefore covered with one foot thick clay puddle, clay being readily available near the site. The puddle was carried from slopes on to the top of the bund. Three layers of sand bags were laid all along the upstream toe of the bund which was further protected from wave wash by providing a network of pilchi mattress tied to wooden pegs driven at the toe of the bund.

The bund as designed and constructed is shown on plate No. 3.

The construction of the 2300 ft. long bund, which required 8,50,000 cft, earth work was started on 4.4.54 and completed on 7.6.54 at a total cost of Rs. 40,609/-.

The mole head spur.

The mole head spur was completed as per details shown on plate No. 3 at a total cost of Rs. 42,000/-.

BEHAVIOUR OF RIVER DURING FLOODS OF 1954

Development of the channel.

There was no flow in the river near the site of the sand bund till the evening of 10th June, 1954, when the first freshet reached the bund.

The water level, at the gauge fixed upstream of the sand bund, rose from R.L. 366.7 at 17 hours to 367.1 at 18 hours on 10,6.54 when the flood water was led into the channel whose bed level at its mouth was kept at R.L. 366.0.

Rapid erosion of the banks of the channel started at R.L. 371.4 at 10.30 hours on 11.7.54, when 3 to 4 ft. deep water was flowing rapidly through it.

The water continued to head up in front of the bund and at 6.0 hours on 12.6.54 the difference of water level upstream and downstream of the bund was more than 9 feet. This remarkable head, it should be remembered, had

been created simply by an earthen bund. The forces held up by it were heavily stressing the bund. It was, therefore, a relief when the channel opened out by rapidly eroding its bed and banks and eased the situation.

The channel carrying a discharge of about 40,000 cusecs at a velocity of 9 to 12 feet per second eroded its banks and widened itself from 30 feet to 120 feet by 18 hours of 11th June and to 350 ft. by 6.0 hours of 12th June.

The channel had not fully developed at its exit and had yet to erode away a few hard clay points which were restricting it on its left and right banks, when the water level started falling at 8.0 hours on 14.6.54. The velocity of flow in the channel then reduced to 5 ft. per second and all erosion stopped.

The back water in the bend near the Right Guide Bund mole head downstream of the sand bund created a still water pocket encouraging silting.

During the five days this first flood lasted, about hundred coolies were kept busy on the job of throwing in sand bags and burnt clay cubes near the junction point of the sand bund and the right bank of the channel (Point P plate 4) to stop the tendency of the raging waters of the channel to erode away its right bank at this point and thereby outflank the sand bund.

After the fall of the river flood on 14.6.54, the work of pitching the slopes of the bank and the sand bund for a length of 100 ft. at the junction point P was taken in hand and burnt clay cubes were hand packed as pitching on the slopes.

Drain cuts 6 ft. wide and 5 ft. deep were made behind the protruding strong clay points on the left bank of the channel and at its exit to assist the erosion of these obstructions at the next rise of the river.

Overtopping of the sand bund.

After a spell of about a month, the river started rising again on 16.7.54. The gauge fixed upstream of the sand bund registered water levels of 362.20 at 18.0, 364.40 at 21.0 hours and 367.80 at 24.0 hours on 16.7.54 and a peak level of 372.0 at 15-0 hours on 17th July after which it started falling and fell to 368.0 on 21st July, 1954.

The maximum discharge which passed through the channel, during this period, at about 9 ft. per second velocity was about 50,000 cusecs.

The hard clay points at the entrance, exit and at some points along the left bank of the channel were quickly eroded away. The channel at its exit widened from 100 ft. to 400 ft.

The river, during this period, had again made incessant severe attacks on the junction point of the sand bund with the right bank of the channel and along this Right bank upto 300 ft. from this point. It would have succeeded in outflanking the sand bund if the staff at the site had not been vigilant and had they not made untiring repeated efforts to check the erosion at this point by throwing in hundreds of bags filled with sand several hundred cubic feet of pilchi mattress and burnt clay cubes.

bank of the river to limit the area of oscillation or "the khadir" of the river on this bank, and if then the two guide bunds are extended to limit the deepest possible embayment behind the right guide bund keeping such an embayment at a safe distance from the bridge aproaches, this problem may be permanently solved.

It is recommended that experiments on the lines indicated above may be carried out for the training works of this bridge and other possible measueres to check the river from coming within a dangerous proximity of the bridge approaches may be experimented upon and devised.

CONCLUSION

This paper illustrates how those exceptional cases to which the Guide Bund system is not wholly applicable can be tackled on the "Still Water Pocket" principle.

It also illustrates that earthen bunds, if properly designed and constructed, can withstand the onslaught and heavy pressure of the raging waters of a river in spate.

The sand bund, in this case, was sited only 200 feet downstream of the mouth of the channel and was thus too close and came in the way of the free expansion of the channel, which if allowed, would have breached and outflanked the bund foiling all efforts of diverting the river. The decision to construct the bund, as explained earlier, was taken as a result of the experiments on the model after the channel had already been constructed. The bund, therefore, had to be sited downstream of the channel that had already been dug and it could not be kept far from the mouth of this channel as that would have reduced the dimensions of the island between the channel and the old course (Marked s on plate 3) making it possible for the channel route to widen, cut into and join with the old course and thus foil all attempts of straightening the river.

It would have been much better if with the siting of the sand bund as decided upon the channel was dug 800 ft. upetream of the bund.

It is, therefore, rocommended for such like works that the siting of the channel and the bund should be such that there is sufficient distance between the two to allow for free expansion likely to result from erosion of the banks of the channel.

As said before, this scheme to train the river, would have failed if the staff at site had not been vigilant and had they not fought a grim battle to keep the sand bund near the mouth of the channel intact by anticipating the undesirable eroding tendencies of the river and taking prompt effective steps to check these tendencies. This paper also, therefore, illustrates that, even under unfavourable circumstances, determination, perseverance and intelligent application of hard work pays and that nature also then helps to produce desirable results.

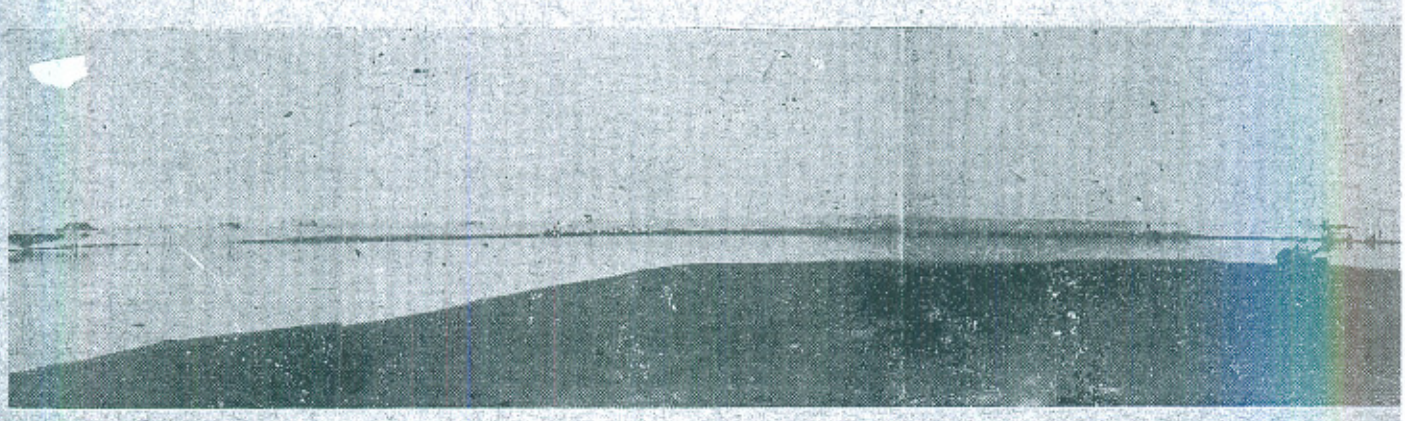
The author wishes to acknowlege with thanks the valuable advice given by Ch. Mhod. Nazir, Director Irrigation Research Institute and Dr. Mushtaq Ahmad Hydraulic Officer, appreciates the hard work but in by his Assistant Engineer Mr. S. D. Malik and the Inspector of works, Mr. S. M. Sharif and their staff; and brings this paper to an end after recording his deep felt gratitude to his Chief Engineer Mr. M. M. Zubair under whose able guidance and benevolent encouragement this work was brought to a successful conclusion



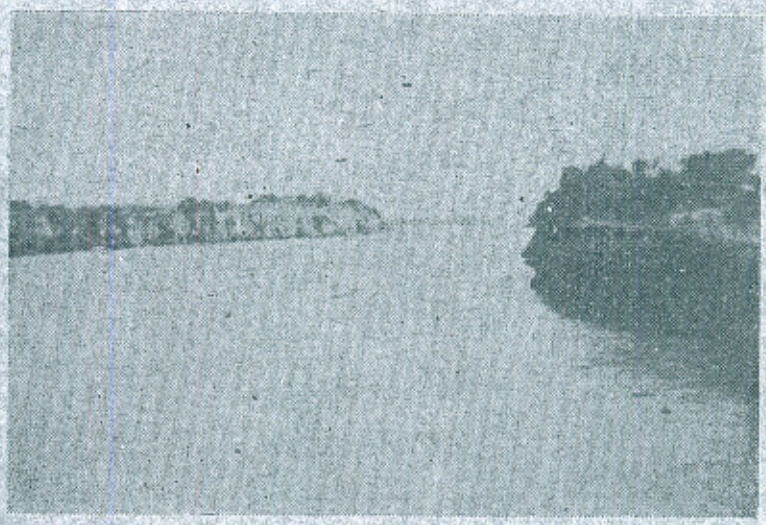
EXCAVATED PILOT CHANNEL



SAND BUND JUNCTION POINT PROTECTION



SAND BUND ON 14-6-1954



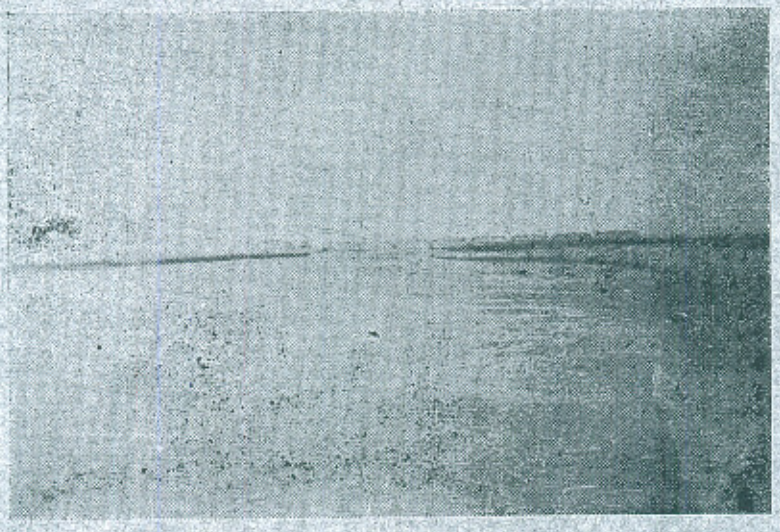
DEVELOPMENT OF CHANNEL ON 14-6-1954



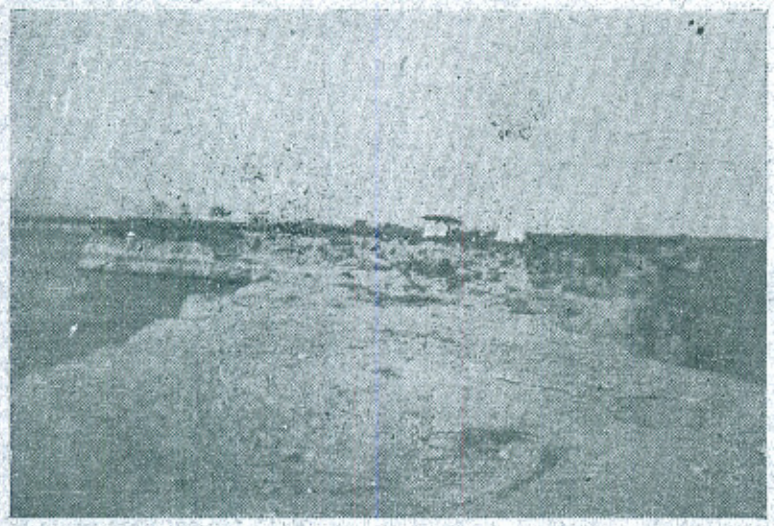
EROSION IN PROGRESS ON 14-6-1954



SAND BUND UNDER ATTACK ON 21-7-1954



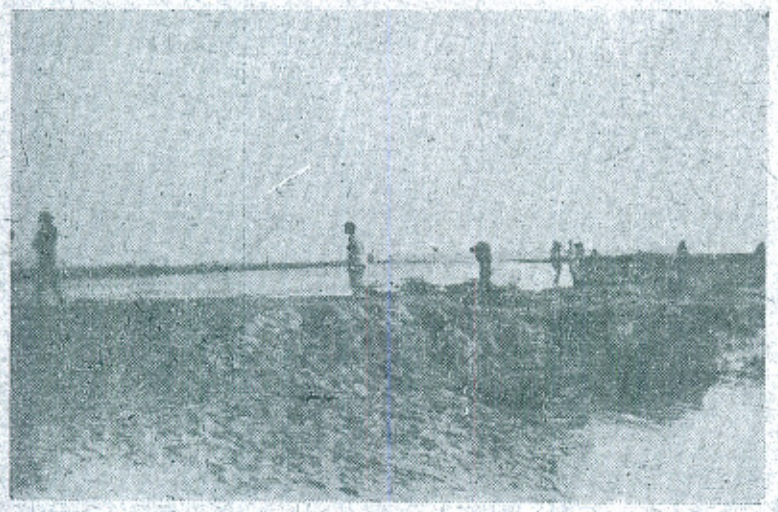
DEVELOPMENT OF CHANNEL ON 21-7-1954



CHANNEL & BLACK WATER
ON 21-7-1954



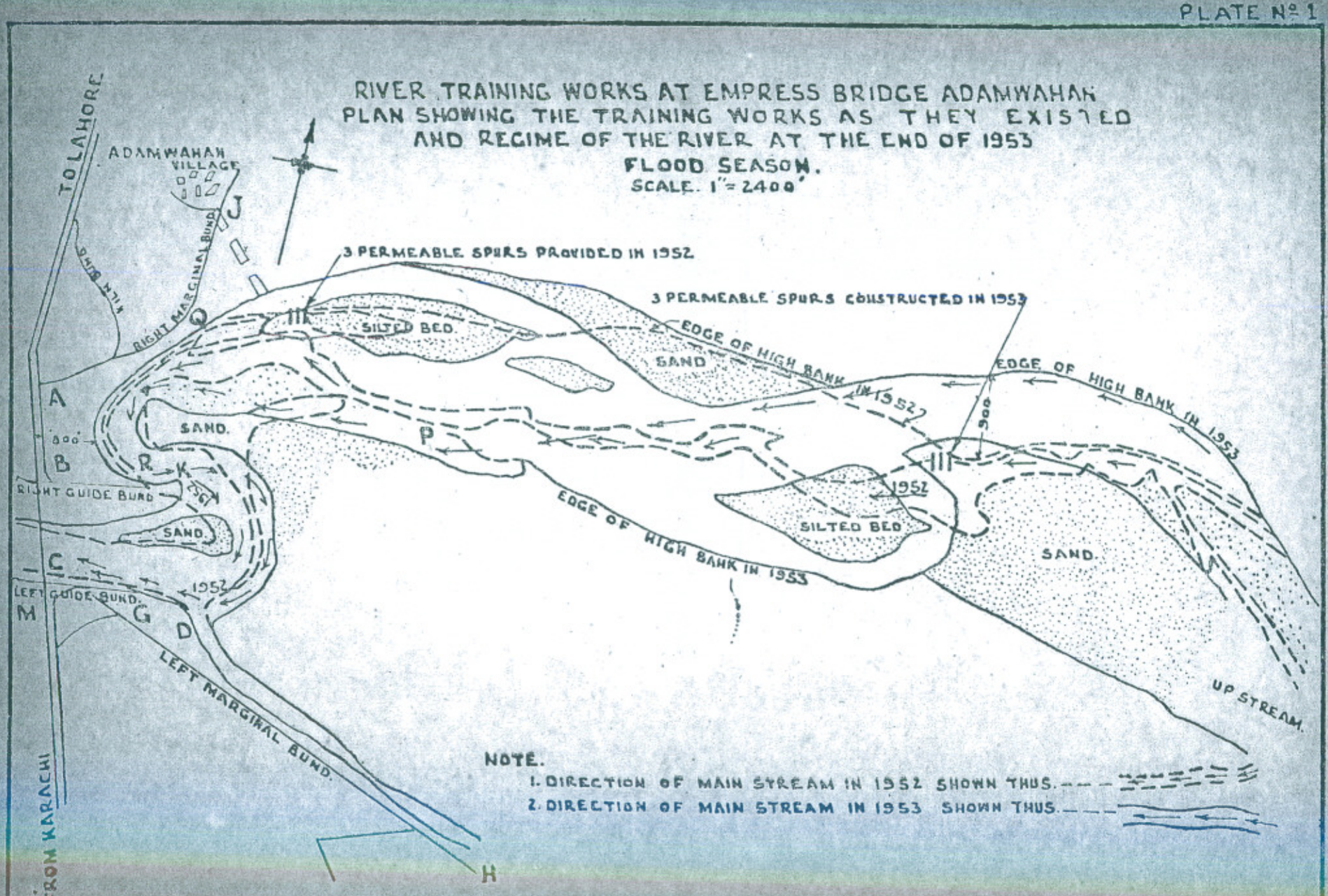
CHANNEL SAND BUND
AND BACK WATER
ON 21-7-1954



CHANNEL BANK NEAR JUNCTION POINT
ABOUT TO GIVE WAY

PLATE No. 1

RIVER TRAINING WORKS AT EMPRESS BRIDGE ADAMWAHAN
PLAN SHOWING THE TRAINING WORKS AS THEY EXISTED AND REGIME OF THE RIVER AT THE END OF 1953
FLOOD SEASON.
SCALE. 1" = 2400'



NOTE.

1. DIRECTION OF MAIN STREAM IN 1952 SHOWN THUS. - - -
2. DIRECTION OF MAIN STREAM IN 1953 SHOWN THUS. — — —

PAPER No. 309

RIVER TRAINING WORKS AT EMPRESS BRIDGE ADAMWAHAN

PLAN SHOWING PROPOSED RING BUND AND PILOT CHANNELS

SCALE 1" = 2400'

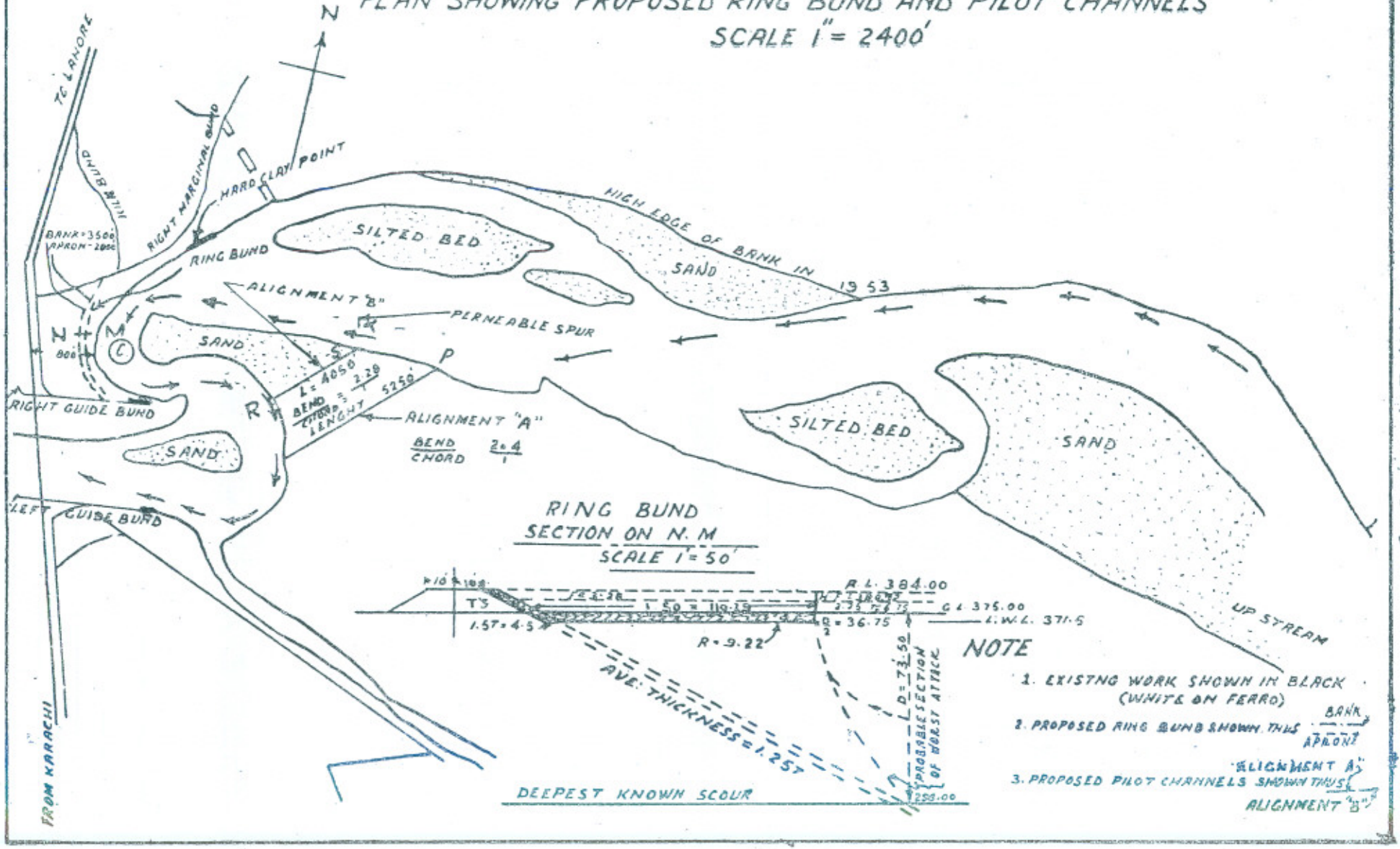
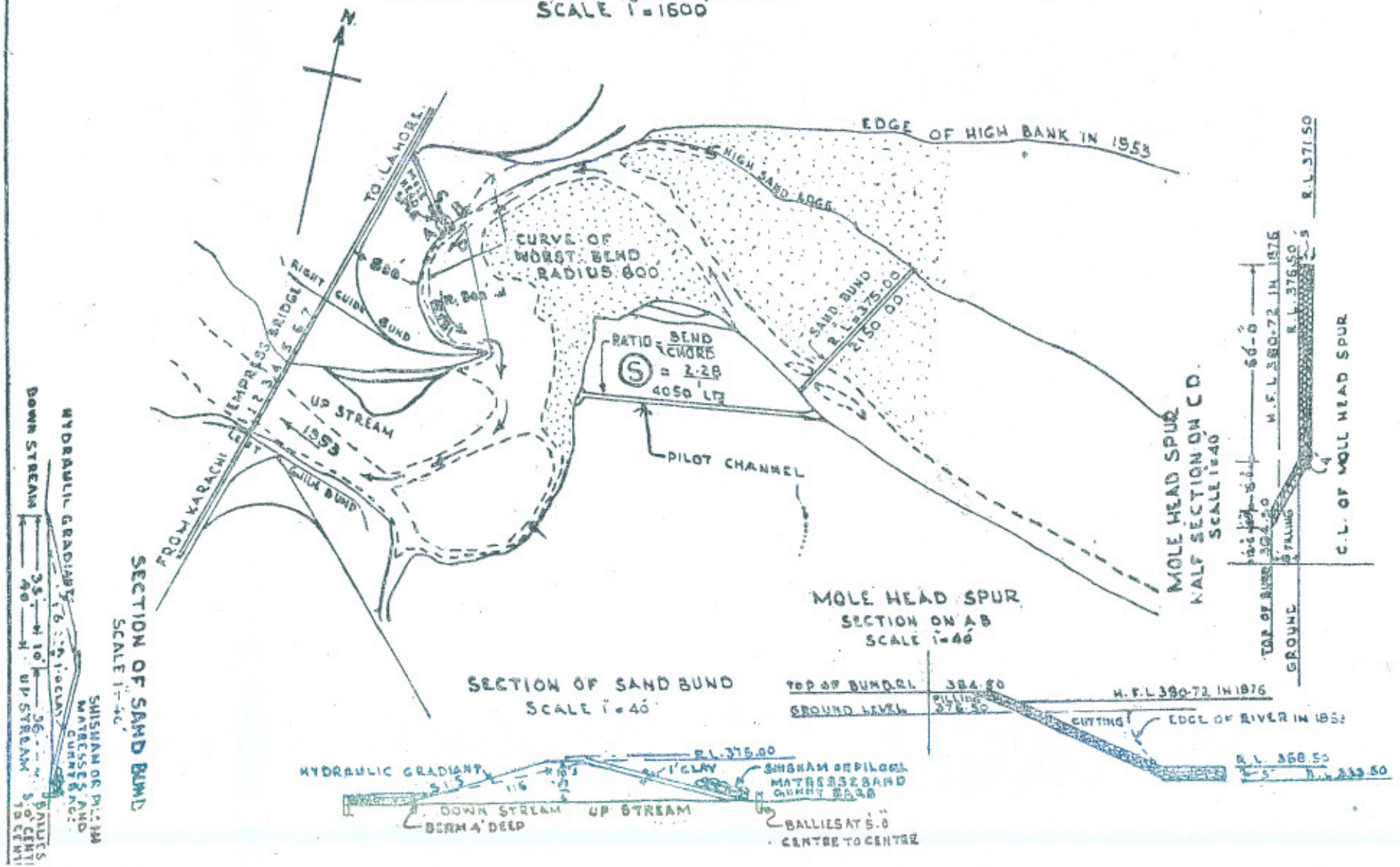


PLATE No. 3.

RIVER TRAINING WORKS AT EMPRESS BRIDGE ADAMWAHAN
PLAN SHOWING MOLE HEAD SPUR PILOT CHANNEL AND SAND BUND AS CONSTRUCTED
SCALE 1"=1600'



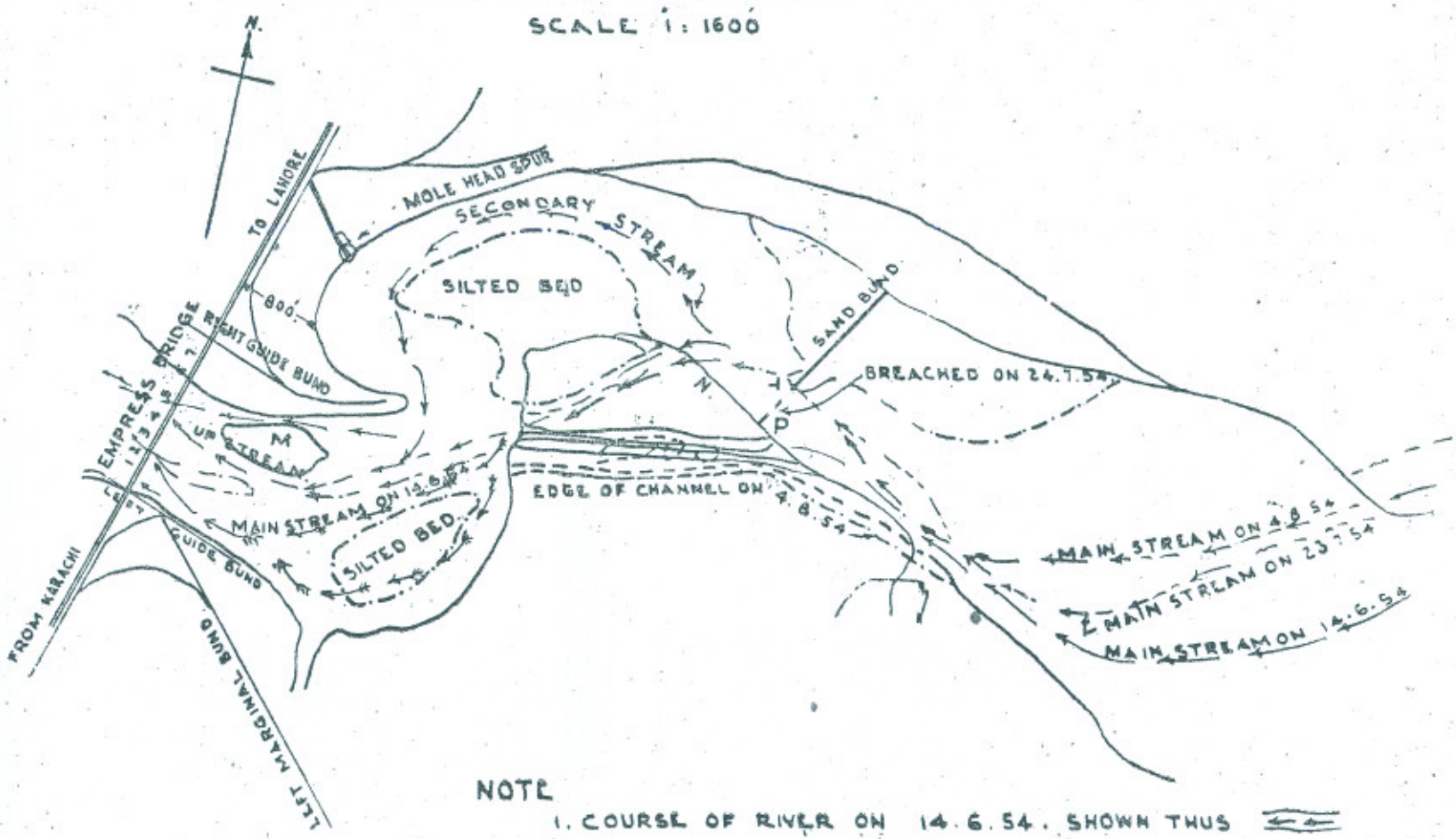
SECTION OF SAND BUND
SCALE 1"=40'

PAPER No. 309

PLATE No 4

RIVER TRAINING WORKS AT EMPRESS BRIDGE ADAMWAHAN SHOWING DEVELOPMENT OF CHANNEL.

SCALE 1: 1600



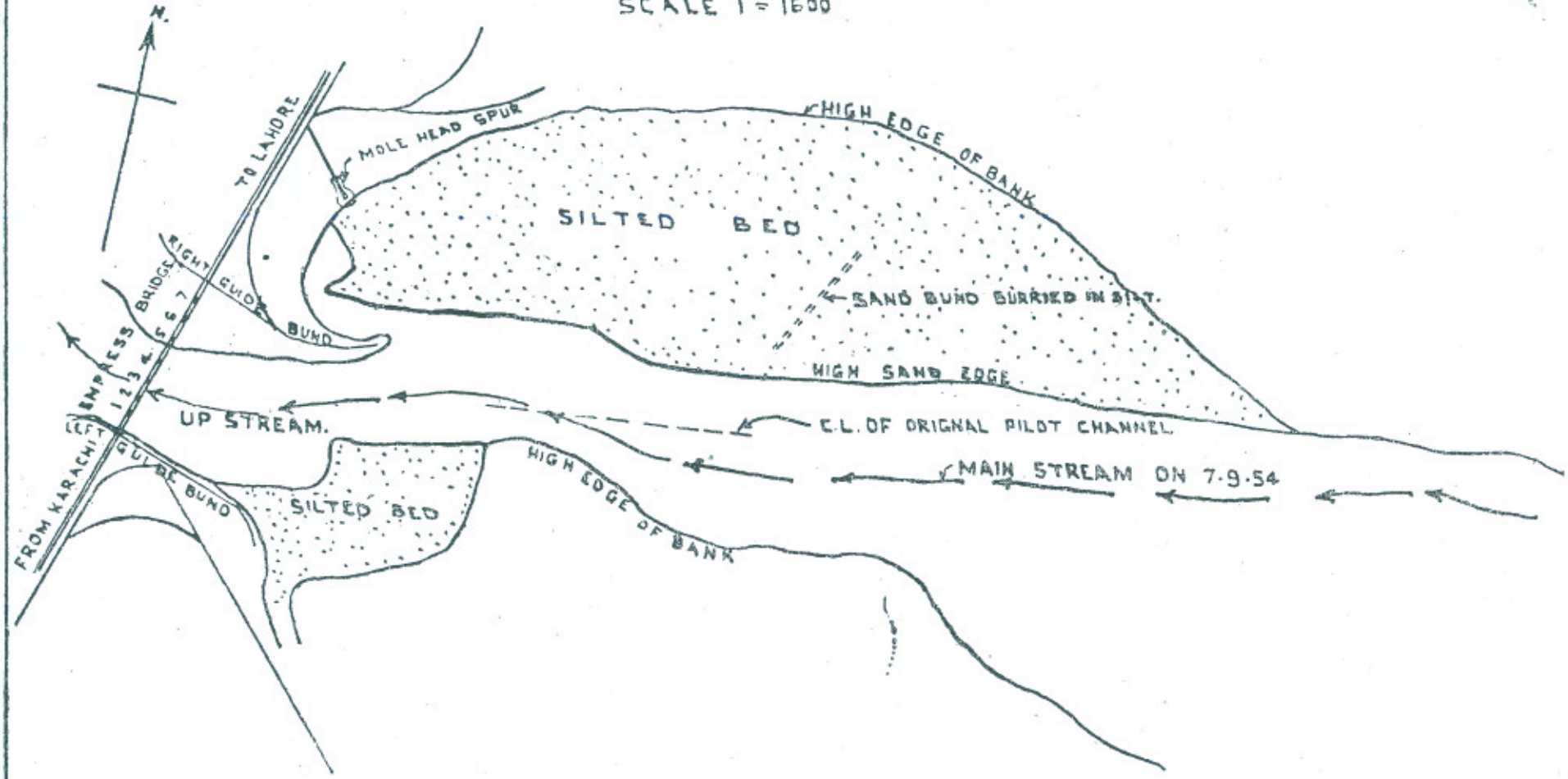
NOTE

1. COURSE OF RIVER ON 14.6.54. SHOWN THUS
2. COURSE OF RIVER ON 23.7.54. SHOWN THUS
3. COURSE OF RIVER ON 4.8.54 SHOWN THUS

PAPER NO 308

PLATE No. 5

RIVER TRAINING WORKS AT EMPRESS BRIDGE ADAMWAHAN
SHOWING FINAL SHAPE OF RIVER AND TRAINING WORKS AS ON 7.9.54
SCALE 1" = 1600'



PAPER No. 309

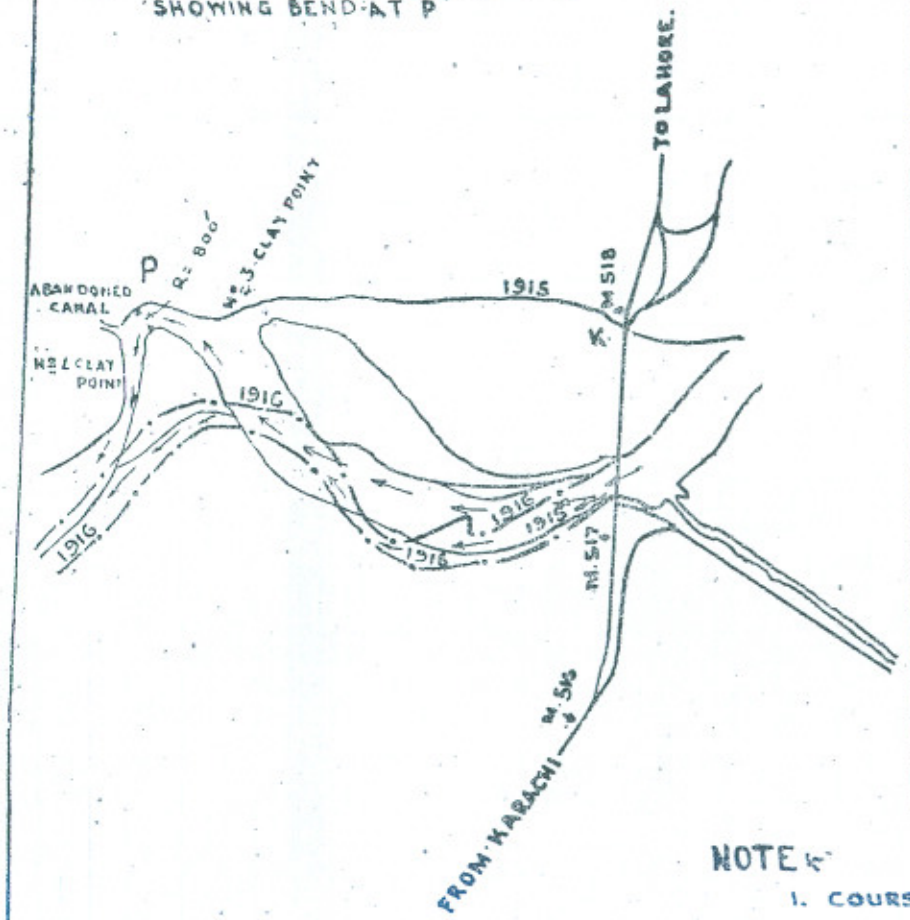
PLATE Nº 6

RIVER TRAINING WORKS AT EMPRESS BRIDGE ADAMWAHAN

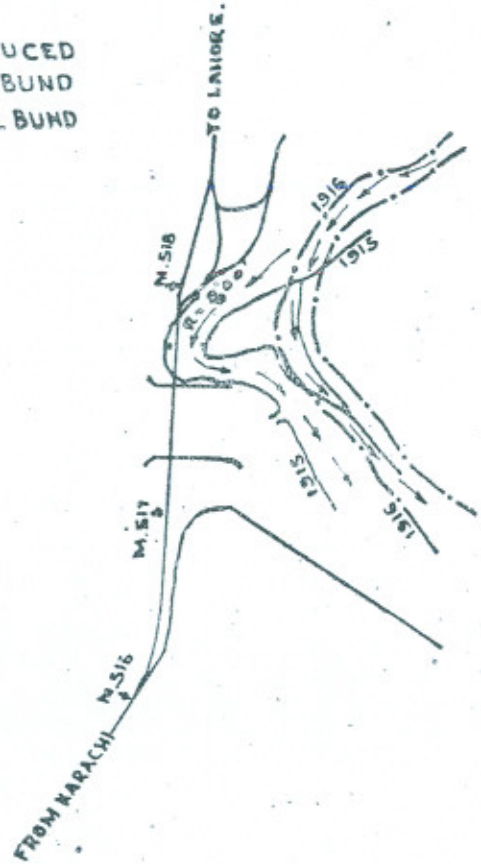
SHOWING COURSE OF RIVER IN 1915-16

SCALE 1"=2400'

SURVEY PLAN OF RIVER 1915-16
SHOWING BEND AT "P"



BEND AT "P" REPRODUCED
BETWEEN RIGHT GUID BUND
AND RIGHT MARGINAL BUND



NOTE:-

1. COURSE OF RIVER IN 1915 SHOWN THUS
2. COURSE OF RIVER IN 1916 SHOWN THUS



PAPER Nº 309