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River Training Works on Indian Bridges

Ouvrages de régulation des rivières à proximité des ponts en Inde

Flussregulierung zur Sicherung indischer Brücken

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SUMMARY

India's mightiest rivers have unusually large widths with meandering tendencies and absence of stable banks, posing enormous problems in siting of bridges across them and protecting the approaches from river attack. A solution has been found by constricting the width of flow of the river by providing artificial earthen banks suitably armoured. The paper discusses various aspects of planning, design and construction of these river training works along with some case studies.

RESUME

Les fleuves de l'Inde sont souvent imposants et extrêmement larges. En l'absence de rives stables, ils auraient tendance à quitter leurs lits. Il en résulte des problèmes énormes pour l'implantation de ponts et pour leur protection. Une solution consiste à contrôler la largeur du courant en réalisant des rives artificielles en terre, efficacement renforcées. L'article traite divers aspects de la conception, du projet et de la construction de ces ouvrages de régulation des rivières, à l'aide de quelques exemples.

ZUSAMMENFASSUNG

Wegen ihrer ungewöhnlichen Breite und Neigung zum Mäandrieren ausserhalb fester Ufer stellen die mächtigen, indischen Ströme enorme Probleme bei der Wahl von Brückenstandorten und dem Schutz der Zufahrten. Eine Lösung wurde in künstlichen, bewehrten Dämmen gefunden, die den Flusslauf eingrenzen. Der Beitrag behandelt einige Aspekte aus Planung, Entwurf und Bau solcher Regulierungsbauwerke anhand von Fallbeispielen.

1. INTRODUCTION

1.1 The geographical disposition of the Indian sub-continent is unique. It is bounded by the high mountains of Himalayas in the North and the peninsula region in the South. It has staggeringly diverse geographical features in terms of terrain, soil and climatic conditions and consequently there are wide variations in the behaviour of its rivers also. While in the southern part of India, known as Deccan Plateau, the rivers have carved deep channels through predominantly rocky strata and stable banks, the rivers in the northern part of the country known as Indo-Gangetic plain flow through deep alluvial deposits and have undefined and unstable banks in most regions. Also, these rivers have meandering behaviour, swinging several kilometres from one side to the other, over the years. The maximum width over which the river meanders during high floods is knwon as the 'khadir' width of the river. An unique example of such meandering behaviour is that of Kosi river which has shifted its course by about 112 Kms. between the years 1736 to 1964. In this movement, about 7700 sq. km. of land in India and approximately 1300 sq. km. in Nepal have been laid waste as a result of sand deposition. For such rivers in the Indo-Gangetic plain, where the width of 'khadir' is much more than the active channel, bridges would have to be constructed across the full 'khadir' width as otherwise there is a danger of these being outflanked. The cost of such long bridges would be prohibitive and, therefore, it becomes necessary to constrict the width of the river by training it.

1.2 In the early days, Indian engineers used the method of providing retired embankments or a series of spurs along the banks on the upstream of the bridge site to train the alluvial rivers. These, however, did not prove to be effective because the spurs attracted eddies and got damaged in high floods, entailing high maintenance cost. An improvement on the system of providing spurs was tried by provision of a pair of long parabolic earth embankments with a comb of spurs running out at right angles. This also proved to be inadequate and expensive for maintenance. Further improvement in river training work was made by constricting the width of the river by providing a pair of embankments, called guide bunds, so that the river flow could be made axial through the bridge. The provision of guide bunds in lieu of spurs proved to be successful and was a landmark in the field of river control and training for construction of bridges. Since then construction of bridges across alluvial rivers in India are accompanied with river control and training measures by providing guide bunds as developed by Bell and improved upon by Spring. The system has proved to be technically sound and cost effective

2. GUIDE BUNDS

2.1 Guide bunds may be defined as artificial earthen embankments constructed in the river bed whose main functions are firstly to train the river and induce it to flow axially through the constricted width of the bridge and secondly to protect the approach embankments from river attack. Guidelines for fixing the salient features and configuration of the guide bund system (Figure 1)required for efficient training of the river have been established and are as follows:

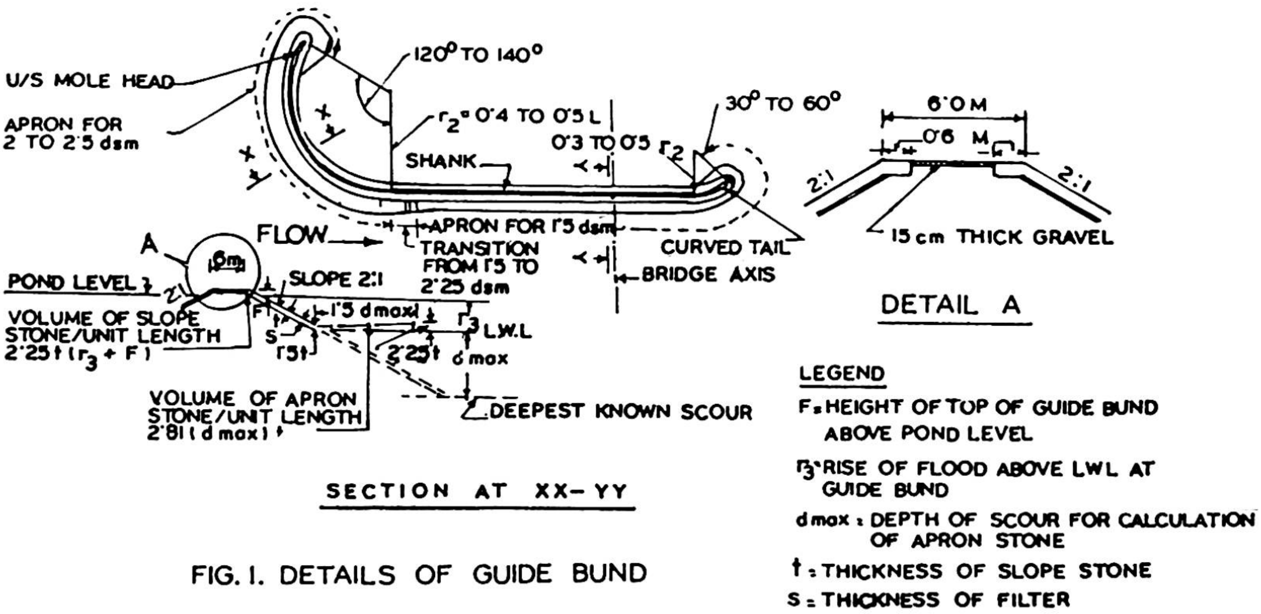

FIG. 1. DETAILS OF GUIDE BUND

2.2 Constriction of width of river: This is decided on the basis of stable channel flow condition, known as regime flow condition, which can carry the maximum discharge of the river. Lacey made observations on several alluvial rivers in India and suggested that the regime width at the highest flood level depends on the discharge and the angle of internal friction of the bed material. He gave an empirical formula for regime width W as:

$$W = C\sqrt{Q}$$

Where W= Regime width in metres

Q= maximum discharge in m^3/sec.

C= A constant, usually taken as 4.8 for regime channels but varying from 4.5 to 6.3 depending upon local conditions of channel flow.

This formula has been found to give quite satisfactory results.

The clear waterway at HFL (High Flood Level) between the guide bunds is fixed as at least equal to Lacey's regime width(W). The constriction ratio may be defined as Total khadir width at bridge site divided by the Regime width or actual waterway provided.

The total length of the bridge (L) is fixed as clear waterway plus the obstructions due to piers.

2.3 Length of Guide Bunds on upstream (u/s)side: The length of guide bunds has to be fixed from two important considerations, namely, the maximum obliquity of the current and permissible limit of embayment of the main channel of the river near the approach embankment behind the guide bund(Figure 2). It is generally fixed on the basis of the radius of the sharpest loop, which the river is capable of taking as shown by the data of the acute loops formed by the river in the past.

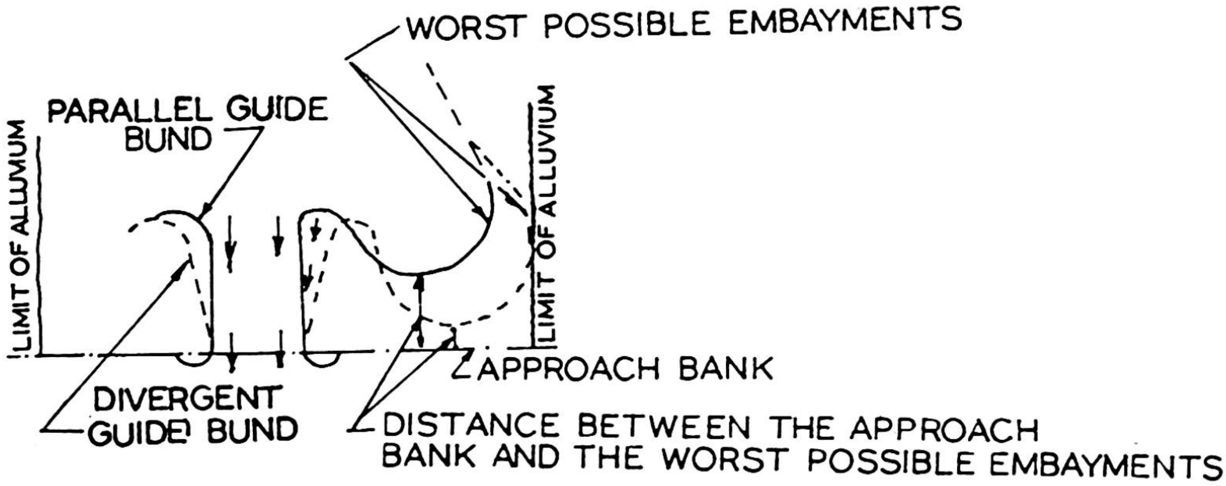

FIG. 2. EMBAYMENT

If survey plans do not indicate the presence of the sharpest loops it may be derived from a mathematical model. After having determined the radius of the sharpest loop the single or double loops are laid out on a survey plan showing the alignment of the approach embankment and high banks. It is ensured that the distance between the anticipated sharpest loop and approach embankment is not less than L/3 where L is the length of the bridge. The upstream length of the guide bund is usually kept as 1.0 L to 1.5L. Guide bunds are generally effective in protecting the approach banks beyond the abutments on either side for a length upto 3 times the length of the guide bunds. Where the constriction is large and the length of the approach banks are greater than three times the length of guide bunds, additional training/protective measures are required to be taken.

2.4 Length of Guide Bund on downstream (d/s)side: On the downstream side of the bridge, the river tries to fan out to regain its natural width. Here the function of the guide bund is to ensure that the river does not attack the approach embankent in the process of regaining its normal width. A length of 0.2 L for the downstream portion of the bund is generally found to be satisfactory.

2.5 Radius and angle of sweep of u/s curved mole head

The radius of curvature of upstream mole head should be such as not to cause intense eddies which may be formed due to constriction of flow. The greater the radius and flatter the curve the less is the possibility of eddy formation. This, however, increases the cost. For proper functioning of the guide bund, radius of upstream mole head is generally kept as 0.4 to 0.5 times the length of the bridge(L). It is usually kept between 150 m. to 600 m. The angle of sweep of the upstream mole head is generally between 120° to 140°.

2.6 Radius and angle of sweep of d/s curved tail: Radius of curvature is generally kept as o.3 to 0.5 times the radius of upstream mole head. Angle of sweep varies from 30° to 60°.

2.7 Top Width: The top width is generally kept as 6 m. to permit passage of vehicles for carriage of materials and inspection.

2.8 Free Board: The free board is measured from the pond level behind the guide bund after taking into account the afflux, kinetic energy head and water slope. The minimum free board is generally kept as 1.5 m to 1.8m.

2.9 Side Slope: Side slope of guide bund is generally determined from consideration of stability of the embankment and hydraulic gradient. Generally a side slope of 2(H):1(V) is considered appropriate for predominently cohesionless materials.

2.10 Slope Protection: The river side slope is protected against erosion by pitching with stones/concrete slabs. The pitching is extended upto the top of the guide bund and tucked in for a width of atleast 0.6m at the top.

2.11 Rear Slopes of Guide Bunds: Rear slopes are also protected against wave splash by provision of 0.3-0.6 m thick cover of clayey or silty earth and turfing. Where moderate to heavy wave action is expected, stone pitching is laid upto a height of 1 m above the rear pond level.

2.12 Pitching on the river side: For the design of pitching on the river side, the factors to be taken into consideration are size/weight of the individual stone, its shape and gradation and thickness and type of filter underneath. The predominant flow characteristic which affects the stability of the pitching is velocity along the guide bund. Other factors like obliquity of flow, eddy action and waves are indeterminate and may be accounted for by providing adequate margin of safety.

2.12.1 The size of stones required on the sloping face of the guide bunds to withstand erosive action of flow may be mathematically worked out from the following equation:

$$d=Kv^2$$

Where

K=a constant, usually taken as 0.0282 for a slope of 2:1 and 0.0216 for a slope of 3:1

d=mean diameter of stone in metres
v=mean design velocity in metre/sec.

However, no stone weighing less than 40 kg. is used in order to prevent stones being carried away by river current. Where the required size of stones are not economically available, cement concrete blocks or stones in wire crates are used.

2.12.2 The thickness of pitching (t) in metres is determined from the following formula:

$$t=0.06Q^{1/3}$$

Where Q= design discharge in m^3/sec.

The thickness of stone pitching is subject to an upper limit of 1.0 m and a lower limit of 0.3 m.

2.12.3 Quarry stone is preferable to round boulders as the latter roll off easily. Angular stones are preferred as they fit into each other and have good inter-locking characteristics.

2.12.4 The stones for pitching are hand placed with the principal bedding plane normal to the slope. The pattern of laying is such that the joints are broken and voids are kept to a minimum by packing with spalls.

2.13 Filter: Filter is provided just below the stone pitching and generally consists of gravel, stone over burnt brick ballast or coarse sand. Provision of filter is necessary to prevent the escape of underlying base material of embankment through the voids of stone pitching/cement concrete blocks as well as to allow free movement of water without creating any uplift head on the pitching when subjected to attack of flowing water and wave action. In order to achieve this requirement, the following criteria are adopted to fix the size of filter material:

$$\frac{D\ 15\ \text{(Filter)}}{D\ 85\ \text{(Base)}} < 5$$

$$4 < \frac{D\ 15\ \text{(Filter)}}{D\ 15\ \text{(Base)}} < 20$$

$$\frac{D\ 50\ \text{(Filter)}}{D.50\ \text{(Base)}} < 25$$

Where D 15 is the size of that sieve which allows 15 percent by weight of the filter material to pass through it, D 50 and D 85 have similar meaning. The filter is compacted firmly. The thickness of filter is generally of the order of 150 to 200 mm.

2.14 Launching Apron

Launching apron is provided to protect the bund from the scouring action of the river. It is formed as a flexible pitching of the river bed, generally placed at low water level (LWL) in continuation of the slope pitching. The stone in the apron is designed to launch along the slope of the expected scour hole so as to provide a strong layer that may prevent further scouring of river bed material and undermining of the guide bund. The apron, when fully launched, is assumed to take a slope of 2(H):1(V) in case of loose boulders or stones and 1.5(H):1(V) in the case of cement concrete blocks or stones in wire crates. The size and shape of apron and the size of stone depends upon the depth of expected scour.

The extent of scour at different portions of the guide bund are adopted as under:

Location	Maximum scour depth to be adopted
Upstream curved mole head of guide bund	2 to 2.5 dsm
Straight reach of guide bund including tail of the downstream of guide bund.	1.5 dsm

where, dsm is the mean depth of scour measured below highest flood level (HFL) .

2.14.1 Width of launching apron generally kept as equal to 1.5 d max where d max is the maximum anticipated scour depth in metres below low water level. The thickness of launching apron at inner and outer ends are kept as 1.5 t and 2.25 t respectively as shown in Figure 1, where t is the thickness of slope pitching.

2.14.2 It may be mentioned that an apron may fail to provide protection to the guide bund if the river bed contains high percentage of silt or clay or where the angle of repose of the bed material is steeper than that of stone as in such a case the apron may not launch properly.

2.15 General considerations

2.15.1 Usually guide bunds are constructed in pairs to guide the river flow between them. Their relative disposition could be parallel, divergent or convergent, depending on river behaviour at the location. (Fig.3)

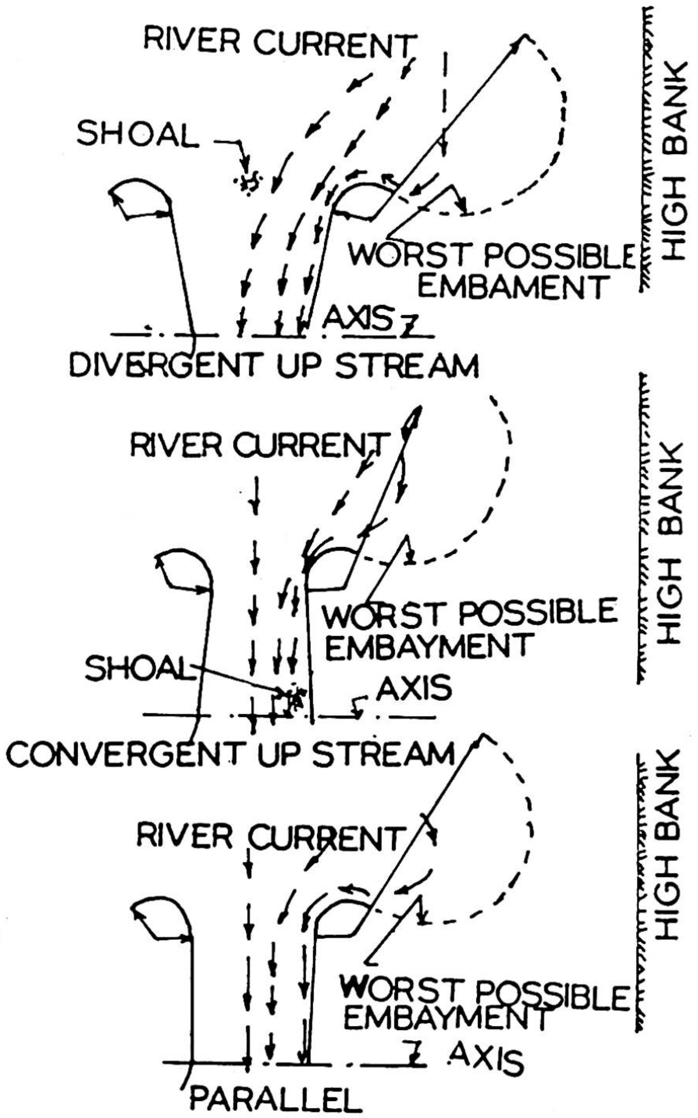

FIG. 3. DIFFERENT FORMS GUIDE BUNDS

2.15.2 Parallel guide bunds with suitable curved heads have been found to give uniform flow from the head of the guide bund to the axis of the bridge and so these are generally preferred.

2.15.3 Divergent guide bunds exercise an attracting influence on flow and they are used where the river has formed a loop and the approaching flow is oblique. However, they have a tendency of shoal formation at centre due to larger waterway between the downstream curved heads. They require a longer length in comparison to parallel guide bunds for the same degree of protection to approach embankemnt.

2.15.4 Convergent guide bunds have a disadvantage of excessive attack and heavy scour at the head and shoaling all along the shank rendering the end bays inactive. These are to be avoided as far as possible.

2.15.5 At certain locations, it may be possible to obtain a firm and stable bank on one side. In such cases only one guide bund on the other side needs to be provided. Obviously the cost of river training is reduced in such cases. This factor influences site selection of bridges, wherein the possibility of having a firm and stable bank in the vicinity of the site is a definite advantage.

2.15.6 Actual siting of a guide bund, however, requires a great deal of understanding of river behaviour. For this, river flow data is required to be studied to find out the most stable section in which the river has been flowing over a number of years. Based on physical site survey and the hydraulic behaviour of the river and the guidelines for the design, as mentioned above, a tentative design of guide bunds and their locations are fixed. Invariably, these are then tested in a model for their performance. We have a number of institutions, where facility for model testing on river behaviour is available. The flow pattern through the guide bund at different stages of discharge is studied in the model. It may be mentioned that in alluvial rivers, directions of river flow may sometime change at lower stages of discharge due to formation of shoals etc. but at design discharge level, flow may be parallel to the guide bund.

2.15.7 The configuration of the bund or the location may have to be slightly modified during model tests so that the flow is more or less axial and uniform between the guide bunds at all stages of discharge. The final configuration as confirmed from the model tests is adopted for execution.

3. CASE STUDIES:

3.1 Brahmaputra bridge near Tezpur

3.1.1 Planning & Design: Bridging Brahmaputra river, one of the major rivers of India has remained a real challenge to engineers especially on account of its hydrology and braided flow pattern. The river has defined banks only in its upper reaches i.e. in Tibet. Once it enters India it flows as a moving ocean from May to October, having flood plain width of 14 to 18 Kms. at most locations. The river carrying an annual runoff of 3,81,000,000,000 cum. also has a high silt load of approximately 0.102% transporting nearly 400 million tons of silt every year, causing wide ranging changes in the flow pattern.

Near Tezpur the river has a khadir width of approximately 5 kms. but the flood spill water extends far beyond this. The river is controlled on the north by Bhomoraguri hill and has a major tributary meeting it about 5 Kms. upstream on the north. These features have resulted in migration of the river to the south and there has been an active channel on the south side during the floods. Considering the facts that (a)any development in south channel may cause severe erosion of the south marginal bund and the river might outflank the bridge (b) large width may result in formation of shoals/islands at the bridge axis, and (c) development of concentration of flow in some bays may cause excessive scour, it was decided to construct a major guide bund on the south side. (Refer Fig. 4)

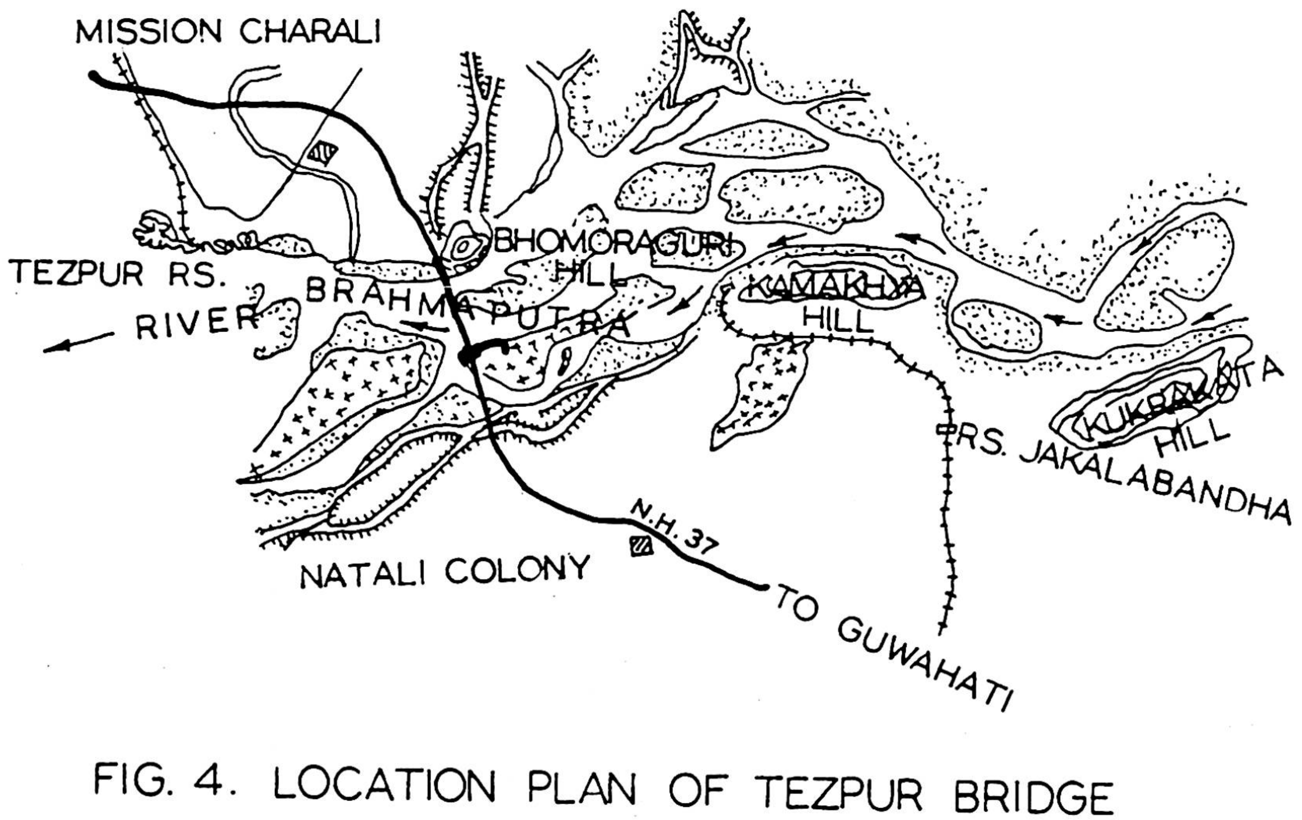

FIG. 4. LOCATION PLAN OF TEZPUR BRIDGE

This guide bund being the first on river Brahmaputra needed extensive studies for understanding its impact over the existing marginal bunds, road approach to the bridge and concentration of discharge, if any, for design of bridge foundations and most important of all, its impact over river flow condition with special reference to Tezpur town on the downstream.

Hydraulic model studies were carried out by U.P. Irrigation Research Institute, Roorkee. For the model studies, about 25 Km on upstream side and 10 Km on downstream side were surveyed in detail in respect of river cross sections, presence of firm points etc. Initially seven proposals with different alternatives of location, length and angle of guide bund were tested in the model and subsequently during the currency of work, additional model studies were required to be carried out due to changes in the river geometry.

Technical features of guide bund as constructed are as detailed below:(Also ref. Figure 5)

Discharge:	92,278m^3/Sec.
Max. Velocity:	4 m/Sec.
Type	Elliptical with equation $\frac{x^2}{(1200)^2} + \frac{y^2}{(560)^2} = 1$
Length	2000 m
Max. Scour depth below LWL	
(a) at the u/s shank	36.24 m
(b) at the mole head	52.27 m
Apron Width	
(a) at the u/s shank	54.50 m
(b) at the mole head	78.50 m
Apron material	Man size boulder (40-60 Kg.) placed in GI wire crates.
Apron thickness	Approx 3 m.
Slope pitching	1.5 m thick with 0.3 m of filter medium
Side slopes	River side 1:2.5 rear side 1:3
Top width	9.0 m.

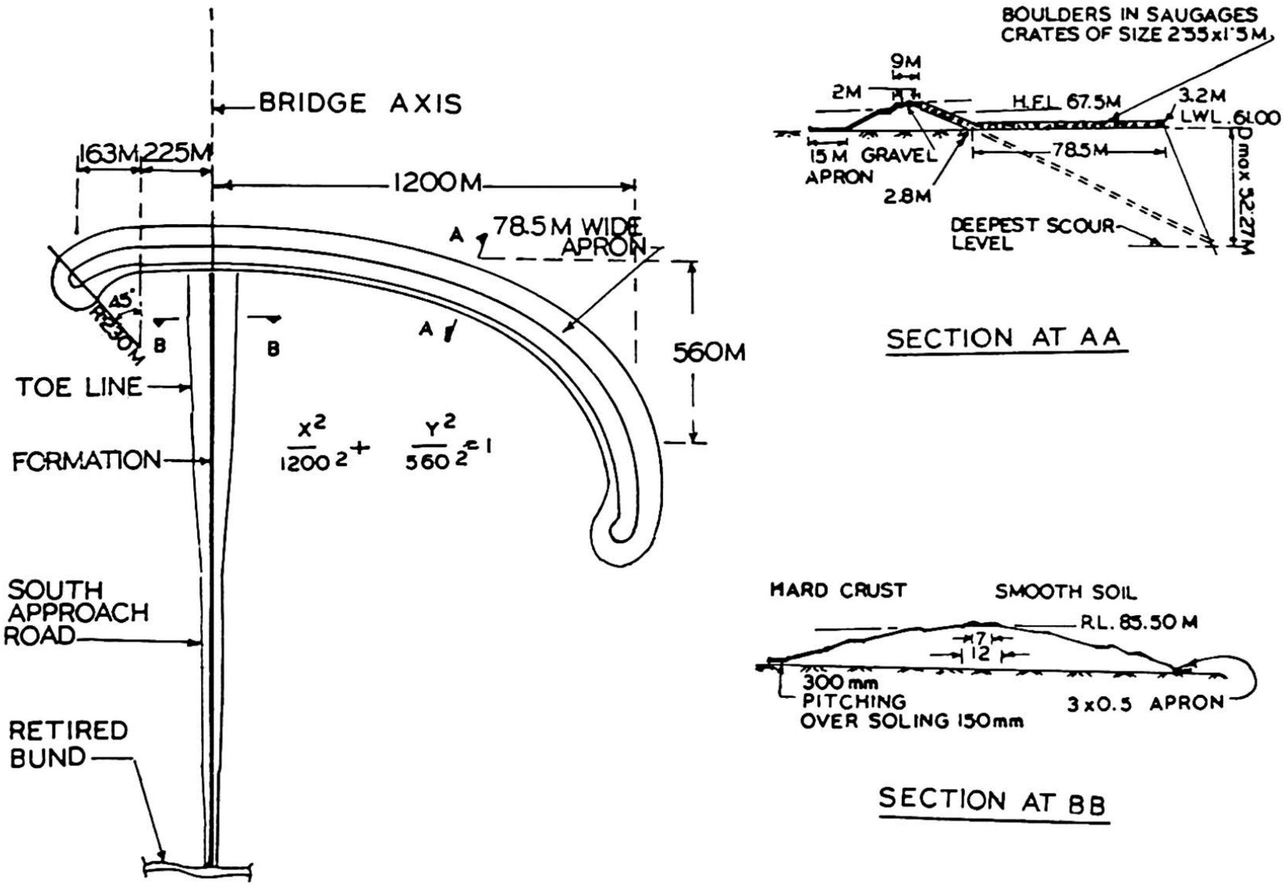

FIG. 5. GUIDE BUND DETAILS OF TEZPUR BRIDGE.

Since the khadir is very wide length of guide bund fixed according to the criteria does not provide enough protection to the approach embankment. It has been observed that the approach embankment is attacked by a single or double loop formation between the khadir edge and the guide bund (Fig. 6). In view of this it was necessary to study the river geometry on the upstream side particuarly in the vicinity of the hillock or permanent point in the left bank and also take into account the radius of the worst embayment for deciding the length of guide bund.

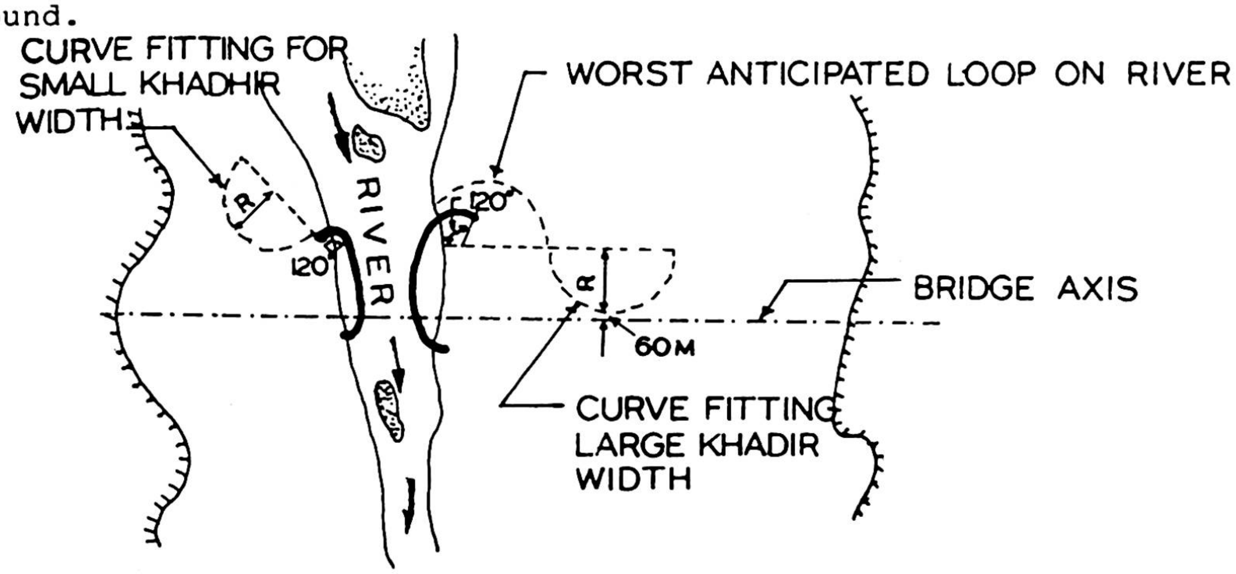

FIG. 6. DESIGN OF GUIDE BUND FROM LOOP CONSIDERATION

The road approach length 1.7 Km lies in the river khadir and has a risk of river forming embayment after leaving the tail end of the guide bund thereby, endangering the approach bank. Therefore, a series of boulder spurs were provided which helped in keeping the river course away from the approach bank.

3.1.2 Construction

Construction of guide bund and approach in river khadir requi detailed planning and construction strategy as the bulk of the work has to be completed in a short time i.e before floods set in. This problem gets further compounded in the case of Brahmaputra river where working period is restricted between November to April. Tezpur guide bund involved execution of about 1.9 million cum. of earthwork and 0.75 million cum. of stone work. Completion upto safe level which is HFL plus free board, required completion of 80% of earthwork and 95% of boulder work in 4½ months. This necssitated very high level of mechanisation. Some of the landmarks of construction were:

- it took 3 years to collect 0.75 million cum of boulders from hill face quarries and just 110 days to lay them in crates, pitching etc.
- average daily progress of earthwork was 12000 cum and of boulders 7000 cum respectively.
- nearly 12 Km of haul roads were developed for movement of earth-moving equipments.

Construction of guide bund became more difficult on account of development of active south channel. A series of river training works like permeable spurs etc. had to be provided to reduce the discharge in this channel. Inspite of these works it was required to close the channel in the month of November for carrying across the construction equipment.

Guide bund and approach has been provided with a well designed drainage arrangement and sufficient stock of reserve boulders has been kept at site to meet any emergency. During the monsoon regular patrolling is done to assess any damage and immediate measures are taken to rectify the same. So far behaviour of guide bund, development of embayment etc. has remained in conformity with the model study results and is expected to remain the same in future too.

3.2 Bramhaputra Bridge at Jogighopa

3.2.1 From hydraulic constructions, the river is stable at Jogighopa due to presence of two hills namely Jogighopa on the

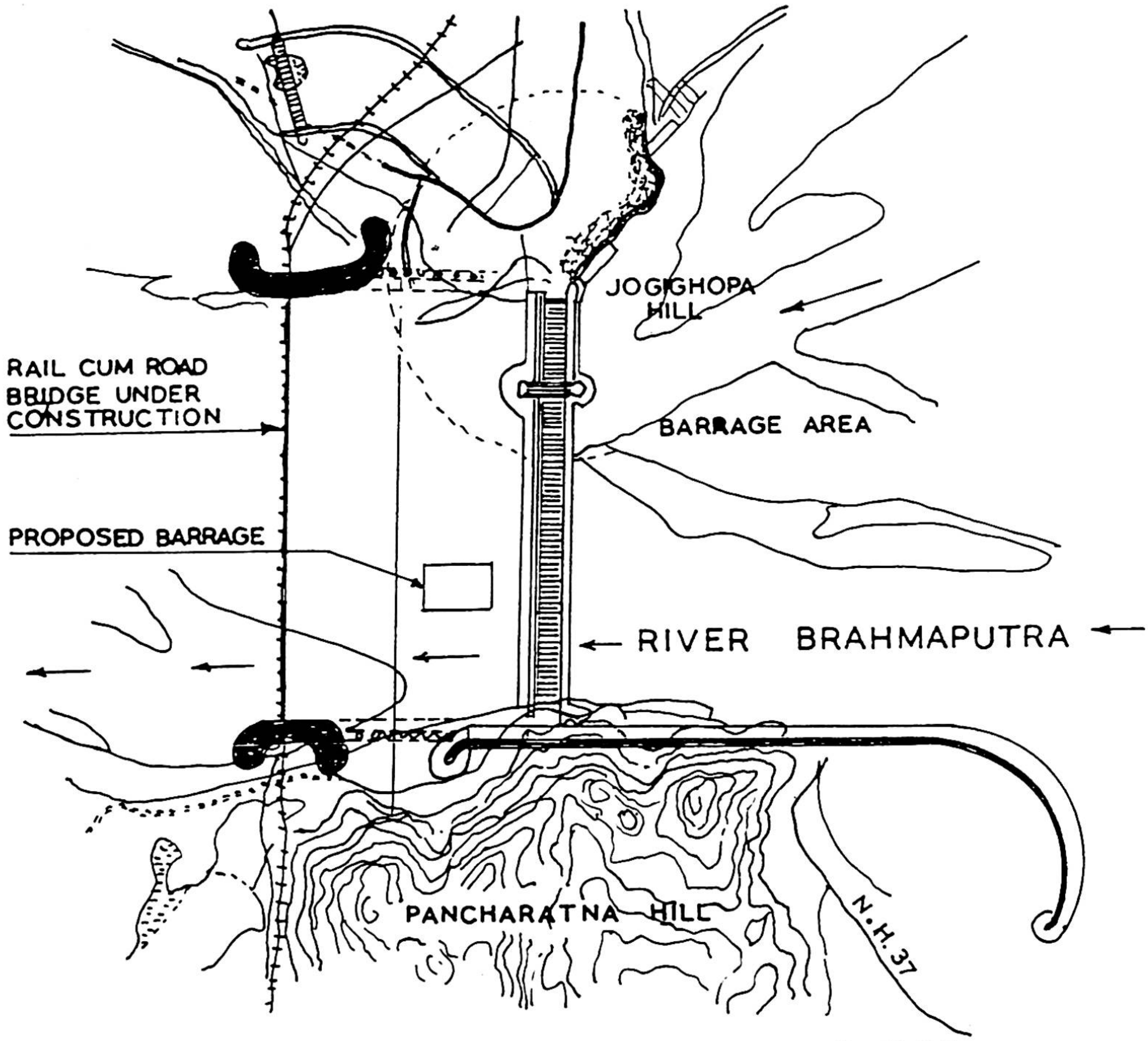

FIG. 7. LOCATION PLAN OF JOGIGHOPA BRIDGE (UNDER CONSTRUCTION)

north and Pancharatna on the south(figure 7). However, this stability is limited to a very small area between the hill noses where the site of the future barrage is located. Immediately after leaving the nose of the Jogighopa hill the river has a tendency to sway towards the north and horizontal control is necessary for any structure to be constructed on the downstream of the proposed barrage. Jogighopa rail-cum-road bridge is sited at 1350 m downstream of the barrage axis. In between, the proposed barrage and the bridge axis, an inland port is to be developed. Combination of the requirements of these multiple structures namely barrage, port facilities and rail-cum-road bridge needed extensive hydraulic model studies for designing length and shape of river training works. A number of combinations (figure 8) were tried out by the research station, with the following terms of reference

- to confirm the bridge waterway from hydraulic behaviour.

- to have final indication of discharge intensities along the bridge.

- to confirm whether there is any probability of increase in the maximum scour around piers on account of port facilities.

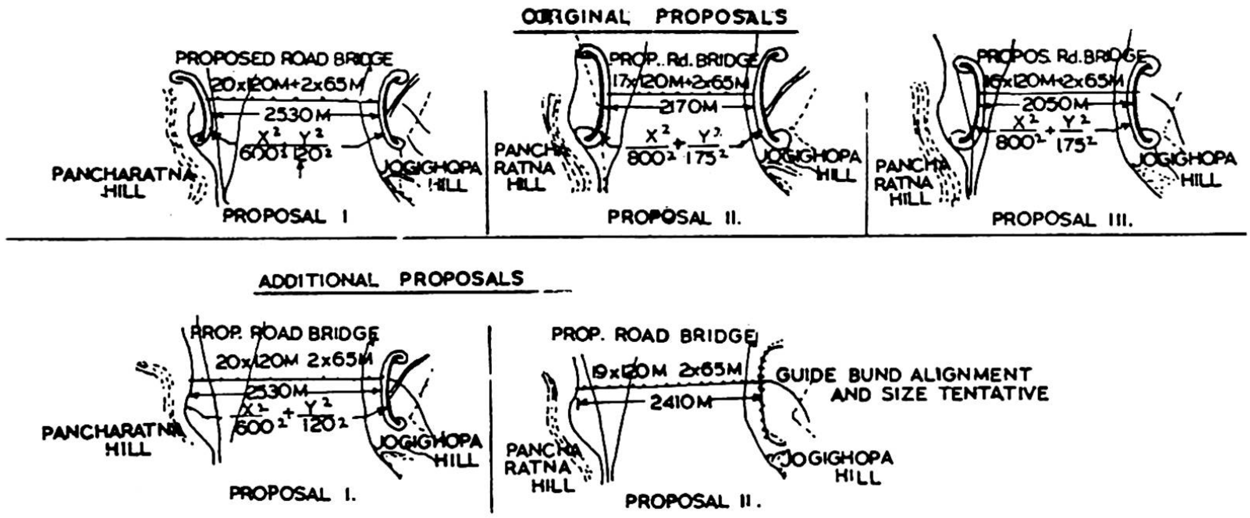

FIG. 8. ALTERNATIVE CONFIGURATIONS OF GUIDE BUNDS FOR JOGIGHOPA BRIDGE.

3.2.2 Model studies indicated that though the river has fairly uniform/stable flow conditions at the location, it is important to provide horizontal control with well designed guide bunds on either side.

3.2.3 Since on the north bank, port facilities are to be developed, a shorter guide bund of 450 m length has been designed. Model studies have also confirmed that due to the two control points, namely, Jogighopa hill and north guide bund in close vicinity, the river does not have any probability of developing full embayment and thus endangering the safety of rail/road approach to the bridge. Both the guide bunds have also been located in line with the planned guide bunds of the barrage so that there is a stable flow condition immediately down stream of barrage. At Jogighopa, south guide bund has been completed in 1990-91 and work on the north guide bund started in Nov. 1991 is expected to be completed by April, 1992. Construction of these bunds is highly mechanised and involved extensive logistic support. Important technical features of Jogighopa guide bunds are as showing in figure 9.

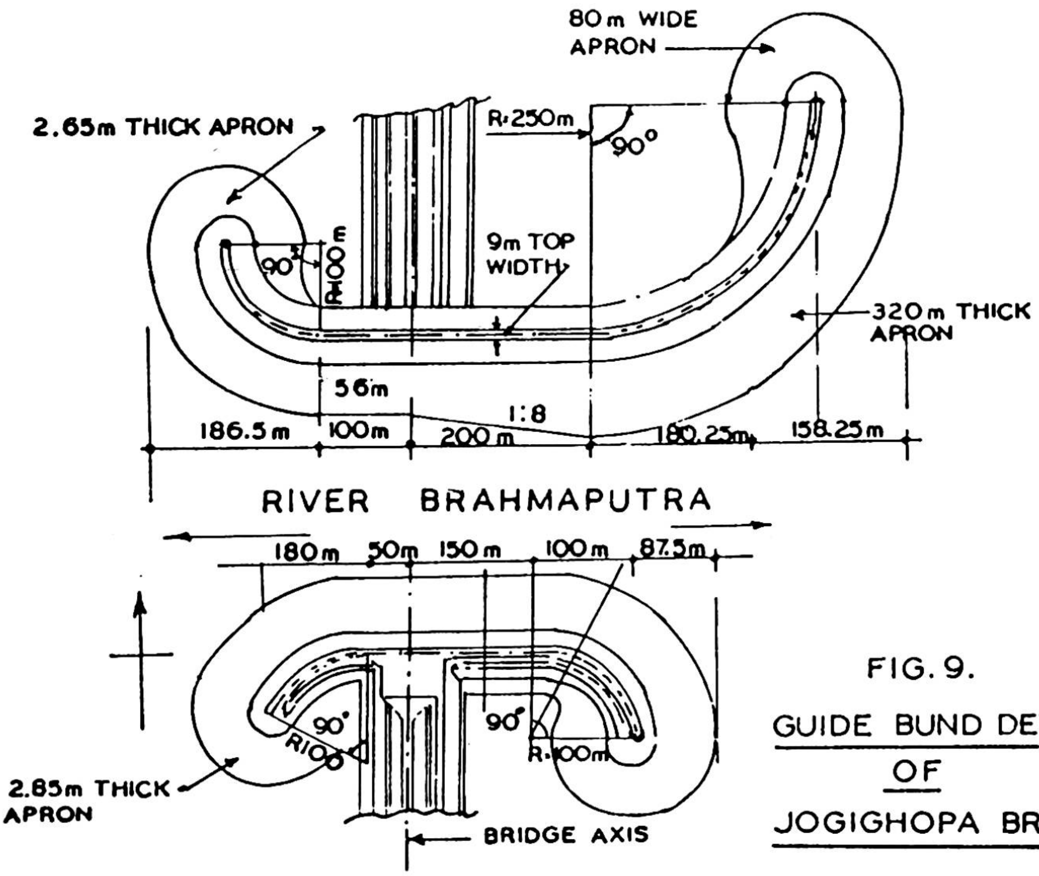

FIG. 9.
GUIDE BUND DETAIL
OF
JOGIGHOPA BRIDGE

3.3 Yamuna bridge at Karnal.

3.3.1 The river Yamuna rises in the Himalayas and flows in a south easterly direction for a distance of about 900 Kms before it joins the river Ganges at Allahabad. A bridge across this river is under construction near Karnal in the State of Haryana. Model studies for the various alternative sites have been carried out before the present site where the khadir width is 2.5 km. was adopted. The design discharge of 16000 cu. m/sec was based on the highest flood discharge of the year 1978 and the overall length of the bridge was kept as 600 m.

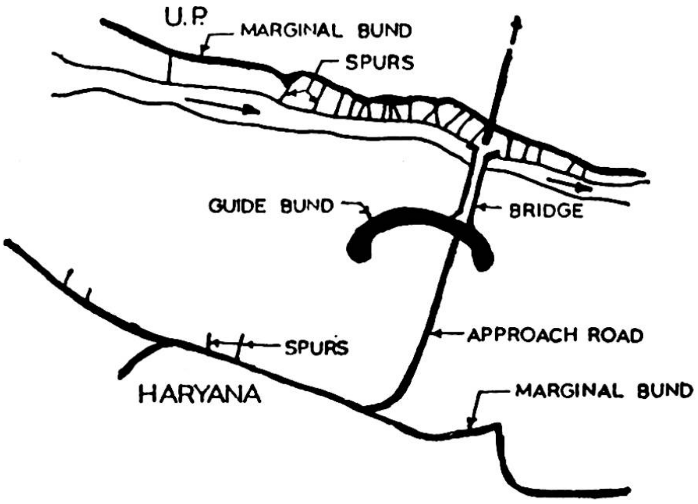

FIG.10. LAYOUT PLAN OF YAMUNA BRIDGE AT KARNAL

3.3.2 It was decided that the marginal embankment and spurs on the left hand side would be raised and strengthened and no guide bund would be provided on that side. On the right hand side an ellipitical guide bund with straight lengths of 400 m and 87 m on the upstream and downstream respectively was provided. The radii of curvature and angles of sweep were respectively 215 m and 90° on the upstream side of guide bund and 90 m and 45° on the downstream side. (Fig. 10)

3.3.3 For the past many years the river was flowing with its main channel hugging the left bank. However, during the floods of 1988 when the work on the foundations of the bridge was already in progress, the river suddenly changed course, shifted by more than 1200 m towards the right and started flowing behind the location of the proposed guide bund. The question of increasing the length of the bridge to cover the new channel of the river was then considered, but it was finally decided to train the river and go ahead with the construction of the guide bund at its originally proposed location (refer Fig. 11)

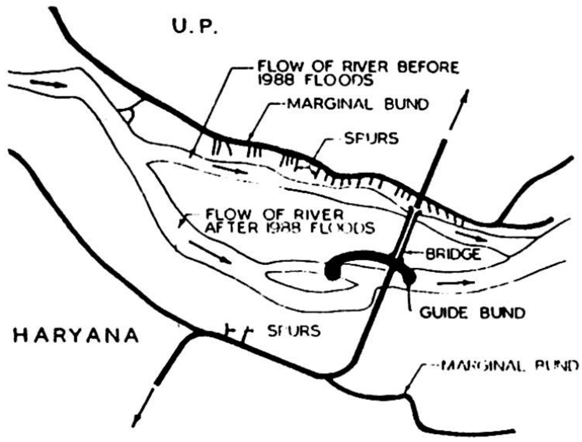

FIG. 11. POSITION OF FLOW OF RIVER BEFORE AND AFTER 1988 FLOODS

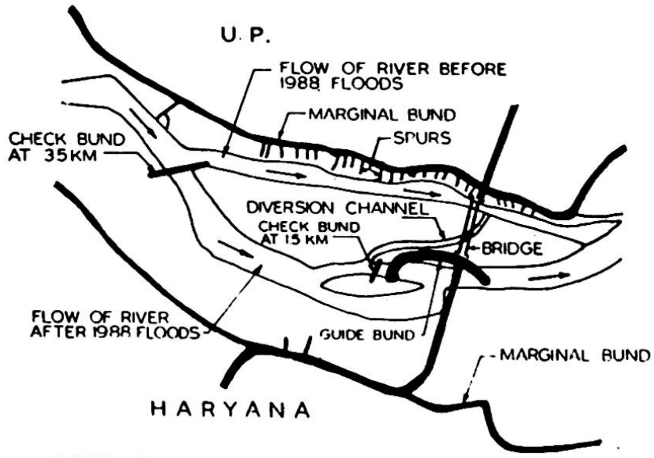

FIG.12 REMEDIAL MEASURES ADOPTED TO DIVERT THE FLOW OF RIVER

3.3.4 During the dry period, a diversion channel was cut in the bed of the river to guide the dry weather flow under the bridge. To achieve this, the flow in the main channel was blocked by construction of a 'check bund' or embankment. The first such 'check bund' constructed about 3.5 Kms. upstream of the bridge site was not successful in diverting the flow and a second check bund about 1.5 Kms. upstream of the bridge site had to be constructed. (refer Fig. 12)

3.3.5 This proved entirely successful in diverting and channelising the flow under the bridge. Thereafter the work of the guide bund and the connecting approach embankment was taken up on a war footing and completed in phases before the advent of the next floods. The behaviour of the river has been well controlled since then and the work on the bridge is now proceeding according to schedule.