TRAINING RIVER NEAR HYDRAULIC STRUCTURES

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ABSTRACT

In view of their enormous costs and safety requirement, it is extremely important that the river training works should be planned, designed and constructed in a scientific manner. Proper understanding of river morphology and river behaviour before and after the construction of hydraulic structures like barrages, bridges etc. is essential. Different methods of river training commonly adopted in India have been briefly described and some of the major deficiencies in the existing design principles have been pointed out with a view to improve upon the existing IS/ IRC codes related to river training. Case histories of river training near Farakka barrage on river Ganga , Kosi barrage and few bridges in India are discussed.

INTRODUCTION

Numerous hydraulic structures like weirs, barrages, bridges, aqueducts etc. are constructed across a river for various benefits like irrigation, hydro-power, communication, cross-drainage etc. For proper functioning of these structures, it is extremely important to train the river so that it moves in its original course without causing any distress to the structure and continue to serve the intended purposes for which the structures were built. It is, however, noticed that often the training measures are adopted by the field engineers without proper understanding of the morphologic behavior of the river resulting in distress to both the river and the hydraulic structure. People living nearby are sometimes subjected to unprecedented miseries due to breach in embankments and erosion of river banks (Mazumder- 2000). Unscientifically designed river training measures may cause more damage and incur more costs of maintenance resulting in wastage of huge sum of public money. At many places, the river is reported to meander excessively causing bank erosion both upstream and downstream of the structure. Afflux embankments are often breached and the river threatens to outflank the structures and change its course. Case histories of a few such important hydraulic structures like Farakka barrage (Mazumder-2001) Kosi barrage (Chitale-2000) and a few bridges (Mazumder-2004[a] , Mittal& Kothyari-2003) are presented with figures and photographs. Behaviour of the rivers near these hydraulic structures (Mazumder-2004) and the conventional river training measures being adopted by engineers in charge of these works are discussed in this paper.

RIVER MORPHOLOGY AND ITS BEHAVIOUR

Proper Knowledge of river morphology and river mechanics (Garde and Raju-2000) is essential for efficient planning, design, construction and maintenance of hydraulic structures. In the following paragraphs, some important aspects e.g .plan form, meandering and stability of a river and its response to hydraulic structures have been discussed.

River Planform

Understanding the behaviour of a river is complicated due to interrelated geomorphologic, hydraulic and hydrologic parameters. The interrelation between channel planform, hydraulic and sediment parameters and relative stability of a river is illustrated in Fig. 1 (Schum- 1981). It may be seen that the different plan forms of a river e.g. straight, meandering and braided depend on the channel geometry, sediment load, slope and discharge of the river. Knowing the mean discharge (Q) and mean bed slope(S_o) of a stream, fig.2 (Lane 1957) helps in predicting the plan form of the stream. Quantitative prediction of stream response to climatological and watershed changes is based on the fundamental relation given by equation- 1 below (Lane-1955)

$$QS_e \;\alpha\; Q_s d_{50} \ldots \qquad \ldots\ldots\ldots(1)$$

where Q is the discharge, S_e is the energy slope, Q_s is sediment transport rate and d_{50} is median sediment size.

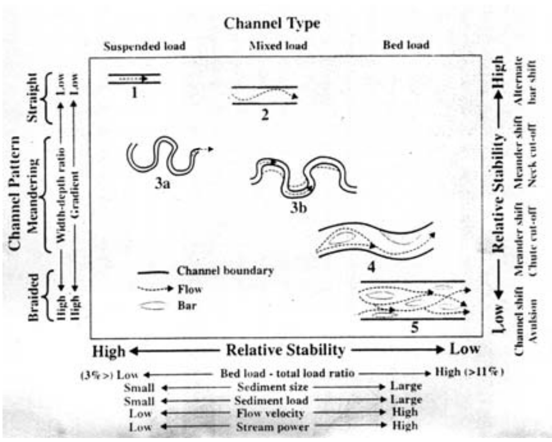

Fig. 1 Interrelation between channel type, hydraulic and sediment parameters and relative stability of streams

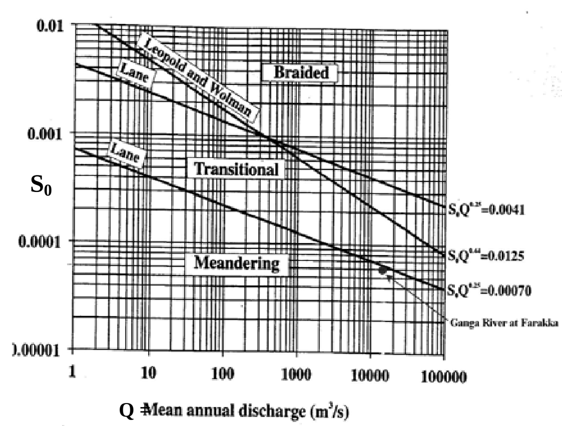

Fig. 2 Interrelation between stream form, bed slope and mean discharge

In all diversion structures, comparatively clear water is withdrawn from upstream (for irrigation, hydropower, water supply etc.) resulting in decrease of both the energy slope upstream and Q downstream. As a result stream power (Q. S_e) gets reduced and hence the sediment carrying capacity (Q_s) is reduced, d_{50} remaining the same. Obviously, sediments will be deposited both upstream and downstream of the structure resulting in gradual increase in bed slope till such time the original stream power is restored and equation (1) is satisfied. Immediately downstream of the structure, there is degradation due to less supply of sediments (deposited upstream) and lack of energy dissipation (Mazumder 1993).

River Stability and Meandering

As shown in fig.2, a non-cohesive stream bed composed of silts and sands is predicted to meander when

$$S_o\, Q^{0.25} > 0.00070 \ldots\ldots\ldots \qquad (2)$$

and braided when

$$S_o\, Q^{.25} > 0.0041 \ldots\ldots\ \ldots.. \qquad (3)$$

Development of lateral instability associated with deposition and erosion on alternate river banks give rise to thalweg pattern. Uncontrolled deposition and erosion ultimately give rise to meander formation as illustrated in fig. 3. Hickin and Nanson (1984) described the lateral migration rate (M) of a meander by the functional relation

$$M = f\,(\Omega, b, G, h, \tau_b) \qquad \ldots.(4)$$

Where Ω is stream power (τ.v), b is a parameter expressing plan form geometry of the stream, G represents amount of sediment supply, h is the height of outer bank (degree of incision), τ_b is the erosional resistance offered by the outer concave bank undergoing erosion. Plotting measured migration rates of meanders (m/year) against relative curvature (r/w, where r is the radius of curvature and w is the stream width) as shown in fig. 4, Hickin concluded that the migration rate is maximum when meander stabilizes at an approximate value of r/w =2.5.

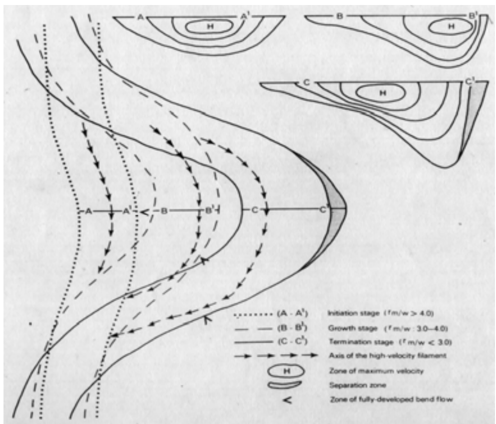

Fig. 3 Lateral Migration of a Meander and stream cross-sections

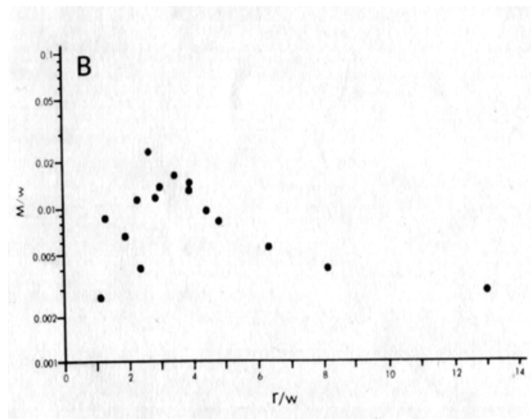

Fig. 4 Variation of Migration Rate (M) with Relative curvature (r/w) in a Meander

Where $M_{2.5}$ is the maximum rate of migration corresponding to r/w = 2.5. Migration of meander as illustrated in fig. 3 occurs on the outer bank side which is subjected to higher stream flow concentration and consequent erosion. Uncontrolled meandering may lead to outflanking of hydraulic structures and flow avulsion when the river shifts its course and it may join other low lying rivers (tendencies as observed in both the case of Farakka and Kosi barrages discussed afterwards).

Response of River to Hydraulic Structures

Understanding the behaviour of a river during the post construction period is extremely important in the proper planning and design of river training measures near hydraulic structures. The process of scouring and silting can result from natural phenomena or from man-made interventions or from change in land use or other reasons like earthquake etc.. The changes may be locally or over a long reaches of the river. For example, construction of levees within the flood plane of river for protecting important places and properties (as in Kosi river discussed later) forces a river to deposit the sediments within the khadir resulting in rise in bed level of the river. Manmade reservoirs encourage siltation and shoal formation upstream and degradation downstream. Backwater behind a dam or a barrage or a bridge (with approach embankments constructed within flood plane) results in loss of stream power, siltation, shoal formations and widening of a stream upstream and the stream may become unstable causing delta like planform, severe meandering (observed upstream of Farakka barrage), cut offs, and sometimes shift in its earlier course resulting in outflanking of the structure. (Figs 5 & 6).

METHODS OF RIVER TRAINING AND DEFFICIENCIES IN INDIAN CODES

Conventional methods of river training popularly adopted in Indian rivers for the purpose of protection and safety consists of (i) Levees/Flood Embankments (ii) Groynes/Spurs (iii) Mattressing /Pitcing / Revetment/Stone Cribs (iv) Guide Bundhs (v) Artificial Cut-Offs (vi) Ground Improvement (vii) Miscellaneous other Devices including scour retards /countermeasures .Except for the last three items, detailed description, design procedure, specification, construction procedures and maintenance of the various other river training measures are given in IS/ IRC codes/guidelines, namely, IS

8408(1994), IS 10751(1994), IS 12094 (2000), IS 14262 (19895), IRC 89 (1997). In the Indian codes/guidelines there are, however, several deficiencies in respect of items as pointed out below.

Computation of Scour Depth

No river training work can be designed without proper estimation of scour depth. The present practice is to find Lacey's regime depth and apply factor of safeties depending on the location etc. These are empirical methods where there is no proper hydrologic/hydraulic analysis of the effects of different parameters actually governing scour. Inspite of a lot of advancement in river mechanics and sediment transport principles and development of several mathematical models for precise estimation of scour depth, the codes continue to prescribe Lacey's method for scour estimation.

Thickness of Stone Pitchings/Gradation/Placement

The major cost in almost all river training works is due to the cost of stone pitching. In India we are still using empirical relations given by Inglis (CBIP-204-1989, IRC-89-1987) for computing thickness of pitchings. Scientific procedure for computation of size and thickness of stones from critical tractive force concept (CW&PRS-1991-92) with due corrections for bank slope, velocity distribution, safety factor, gradation and shape of stones etc. (US Army Corps of Engineers-1989) should be adopted for finding proper thickness and size (or weight of stones) in the design of revetments/pitching.

Apart from proper size and thickness, proper gradation of stones is important for the effectiveness of stone pitching. Uniformly graded stones has large voids through which filter and fine subsoil materials may be winnowed due to dynamic suction and seepage flow from saturated banks after the flood level in the river subsides. Proper placement of pitching/mattresses/cribs etc. so that they fully cover the areas to be protected is very important, especially when placed under water (as in the case upstream of barrages). Cribs / stone cratings of small size (2m x 2m as used upstream of Farakka barrage) dropped from top of water surface may not fully cover the whole area uniformly, resulting in winnowing of base materials and consequent undermining of protective works.

Filter Design

Proper design of Filter provided underneath revetments is essential for the safety of all the protective works described above. IS code (IS: 8237-1985) and guidelines by IRC (IRC: 89-1997) specify the filter design which should be followed when pitching are laid in dry bed. In underwater construction, however, it is not possible to provide such graded filter and use of fascine/willow mattress (tarja mat woven from bamboo skin is used in Farakka barrage) etc. are commonly used as a substitute of filter. Thorough testing in laboratory regarding their effectiveness as filter is a prerequisite. Geo-textile Filter (Tripathy 2003) or geo- jute filter with proper mesh size as prescribed in IRC and IS codes are far better substitute for filter and they are more durable. When the mean size of bed material is less than 0.037mm, woven jute or textile filter is discouraged due to possible clogging. In such situation, loose non-oven material is recommended.

Launching Apron

Launching apron composed of loose stones is always provided (as prescribed in our codes) in order to protect the toe of levees, guide bundhs, groynes etc. with the idea that when scouring will occur, the flexible stone pitching will be launched to protect the scoured surface. It has been observed that under water launching is never uniform especially where the bed is stratified and floods of different magnitudes occur after the launching apron is laid. This will obviously help in winnowing of base materials underneath and undermining of the protection works. Cut-off walls or sheet piling or wooden/bamboo piling at the toe with sand bags and geo-textile filter at the back will be much more effective compared to launching apron of loose stones.

Shape and Length of Guide Bundhs

Guide bundhs are really transition structures connecting the bridge with flood plain of a river. The connventional straight (or parallel) guide bundhs, as recommended by Bell, has an upstream sharp head abruptly ending within the flood plane**.** It causes high flow concentration near the head. and deep scour at the head often resulting in damage to the guide bundh. Elliptical guide bundhs with proper ratio between major and minor axes (Lagasse, et al. -1995) is a better hydraulic design. As seen in fig.7, Lagasse used three parameters, namely, Q_f, Q_{30} andV_{n2} in fixing the guide bundh length upstream of bridge, where Q_f is the lateral or floodplain discharge intercepted by the guide bundh, Q_{30} gives the discharge in 30 m of the stream adjacent to the abutment and $V_{n2} = Q_t/ A_{n2}$ where Q_t is the total design discharge of the river at the bridge site and A_{n2} is the normal cross-sectional area of flow under the bridge at normal design high flood. Higher the V_{n2} value, longer is the length of guide bundh, which is quite rational. In the Indian codes, however, length of guide bundh is about 1.25 L where L is the span of the bridge. This means that smaller the span or higher is $V_{n2,}$ less will be the required length of guide bundh. This is just opposite of Lagasse's recommendations and is quite irrational.

Backwater and Sedimentation with Levees

Levees constructed within the flood plain of a river (as in Kosi River) causes loss of flood plain/valley storage causing backwater and usually a rise in normal HFL. Stream power per unit weight per unit width (QS_0) is reduced considerably due to backwater resulting in deposition of sediments within the khadir bounded by the levees. BIS guidelines for planning and design of levees (IS:12094:2000)do not even mention of backwater computations needed for fixing top level of levees, leave apart computational methods. Code should also prescribe the necessity and design procedure for embankment sluices essential for drainage of flood protected areas since most of the damages to crops occur due to submergence/waterlogging owing to lack of proper drainage.

Planning and Design of Groynes/Spurs

Properly designed and appropriately located spurs not only protect the bank under river attack, they encourage siltation due to dampening of flow and eddy formation. When a river meanders excessively resulting in alternate bars and thalwegs, depth of flow reduces at the crossings and the manoeuvring of the vessels in such a highly tortuous path becomes extremely difficult. Properly planned and designed spurs/groynes field help in reduction of curvature and khadir width resulting in increased depth of flow and a smooth navigable path. BIS code (IS: 8408:1994) provide guideline for planning and design of groynes in alluvial rivers- both permeable and impermeable types. The length, spacing and protective arrangements described in the IS code, however, are applicable for solid impermeable type spurs in a straight channel only.

Local maximum scour depth at the head of a spur is governed by a large number parameters e.g. length and geometry of spur, bed and bank material characteristics, approach flow characteristics etc. which are not considered in Lacey/Inglis type equations prescribed in the codes. CW&PRS Platinum jubilee publication (1991-92) gives improved method of computation for scour. Construction of long impermeable type spurs should be discouraged since they not only create a large differential head across the spurs and loss of their structural stability, high flow concentration at the head cause excessive scour leading to their progressive failure and wash out. Apart from the scour, such long spurs may create river instability due to excessive restriction of waterway (Mazumder-2002) when the main flow may move in any direction contrary to flow deflection as assumed by most of the river engineers at site.

CASE HISTORIES

River behaviour and the training measures adopted to control the river near a few hydraulic structures are briefly discussed in the following paragraphs.

Farakka Barrage on River Ganga

The river has developed a sharp meander upstream of the barrage resulting in unprecedented problem of erosion in Malda district lying on the outer side (left bank) of the meander. On several occasions,

the marginal embankments were breached causing colossal flood damages (Mazumder 2000). The river has moved about 8 km inside Malda district wiping out thickly populated villages near the left marginal embankment. 450 people died and property worth about rupees 1000 crores was damaged in 1998 flood alone. 8 nos. of retired embankments and 27 nos. of spurs which were constructed to protect the marginal embankment upstream of the barrage have been washed out . In case of any avulsion of the mighty Ganga upstream, the barrage will be ineffective and it will cause disaster to Malda district including the National highway (NH-34), Railway line and afflux bund protecting Malda town .
Downstream of Farakka barrage, the river has scoured the Right Bank in Murshidabad district of West Bengal. The river is threatening the existence of several towns located on right bank and loss of very fertile land. If the erosion continues further, the river may merge with Feeder canal defeating the very purpose of the barrage. Railway line, NH-34 will be washed out. 96 nos of submergible type boulder spurs were constructed to arrest erosion from Farakka to Jalangi, a distance of about 100-km. Several spurs and revetments have been washed out.

A master plan of riverbank protection both upstream and downstream of the barrage has been drawn at a cost of about Rs. 927 crores as per the recommendations of Pritam Singh and Keskar Committee. The conventional method of river training by providing embankments, stone pitching, spurs, submerged bed bars etc. have miserably failed since the engineers in charge are unable to analyse the hydraulic and morphologic factors interplaying with the barrage. It will be desirable to conduct indepth study of the problem before spending such a huge sum of money. Perhaps, use of permeable type groins would have given better results. Much of the problem, however, is due to deposition of sediments and formation of shoals upstream. Some alternative methods of river training were recommended for protection of the bank and safety of the barrage (Mazumder 2001).

Kosi Barrage on River Kosi

The river is aggrading both upstream and down stream except a short stretch immediately downstream of the barrage where it is degrading. The principal cause of aggradation is the tremendous sediment load brought by the river annually, estimated as 95 million tons on an average. Earlier before the construction of the flood embankments, a large portion of the sediments used to be deposited in the flood plain. After the construction of embankments, most of the sediments are getting deposited on the khadir bounded by the flood embankments. Because of its instability, the river has caused breaches of both embankments and it is threatening to create an avulsion and trying to merge its course with low level rivers on the east side. In spite of constructing 284 numbers of impermeable groynes to train the river, breaches of the banks have occurred several times causing floods and damages to the crops. If the river is not controlled both upstream and downstream of the barrage, the river will continue to attack the embankments. Training of such an unstable river is going to cost so heavily that it will be almost impossible to contain the river within the flood embankments. (Chitale, 2000) .

River Behaviour near Bridges

A large number of major, medium and minor bridges have been constructed on rivers all over the country. For economy, the waterway provided under the bridges is often restricted and is sometimes less than the normal waterway corresponding to design flood discharge. In the north and north east India, the Khadir width of a river is found to be much larger than the regime width due to meandering or braided type channels. In such wide flood plains, the waterway is usually restricted to Lacey's regime width or even less by constructing approach embankments and guide bunds. Due to asymmetric approach flow upstream of the bridge, the river may hug on to one of the banks and deep embayment occur near the head of guide bunds leading to high erosion and damage of the approach embankments and the guide bunds. Fig. 8 illustrates outflanking of a bridge on stream Danab Khola in Nepal, which was built over a large number of hume pipes. Additionally, transition structures made of stone gabions were constructed near the abutments causing high degree of restriction of normal waterway. Fig.5 illustrates development of a bowl form both upstream and downstream of a bridge on a stream in M.P. state highway, due to high degree of restriction of waterway. The stream may finally outflank the bridge on either side of the abutment. Sometimes, there is high tortuisity of flow upstream as shown in fig.6 observed in Ekti river on NH-31C.

UPDATING IS /IRC CODES RELATED TO RIVER TRAINING

Keeping in view the developments that have occurred in river mechanics and river morphology over the years after Lacey/Inglis developed their regime theories and the discussions made above, it is necessary to update the various relevant codes/guidelines related to planning and design of river training works, namely, IS 8408:1994,IS 10751:1994, IS 11532:1995, IS 14262 and IRC: 89-1997.

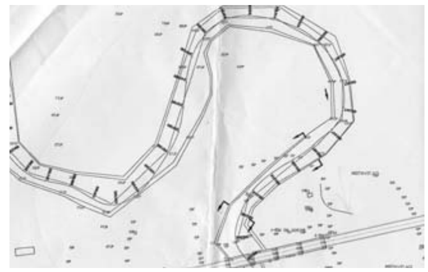

Fig. 5 Formation of a Bowl upstream and downstream of a Bridge (on M.P.State Highway) due to excessive restriction of waterway

Fig. 6 Meandering of Ekti River Upstream of the Bridge on NH-31c

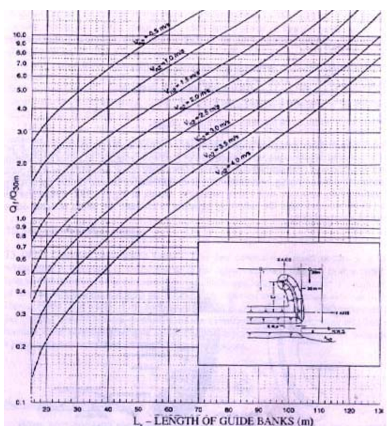

Fig.7 Relation between length of guide bundh , Q_f / Q_{30} and Q_{n2}

Fig. 8 Outflanking of bridge on river Danabkhola in Nepal

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