RIVER TRAINING WORKS

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1. INTRODUCTION

Water flowing through rivers is one of the most important natural resources for survival of mankind and other living beings. Historically, all civilizations and pilgrimages in the past have developed in areas around water bodies like rivers which occupy a prominent place at every stage of all human development. Some of the most important usage of river and river water are:

a) Municipal and domestic use

b) Agricultural and Industrial use

c) Power generation – Hydro, thermal, nuclear etc.

d) Drainage – Storm water run off, municipal wastes etc.

e) Life support for fish, animal, forests other flora and fauna

f)Worshipping, transportation, recreation, health resorts etc.

g) Recharging ground water at high stage and maintaining dry weather flow at low stage of

Except some rivers in the Himalayan region most of the rivers in India are rain fed. Unlike Europe, snow fed rivers are only a few flowing from high altitude in the Himalayas e.g. Ganga, Yamuna, Brahmaputra, Sutlej etc. where substantial amount of runoff are from snowmelt, especially during summer and lean season. Run- off distribution in most of the rivers are directly related to distribution of rain fall/snow melt. High intensity of rainfall/snowmelt for a prolonged period causes flooding and drought occurs due to scanty and insufficient rainfall. Flooding brings about damages to crops and other properties besides loss of life, disruption in communications etc. Losses are more as the people encroach on flood plains for proximity of water body, fertility of land, cheap land etc. When the river is in high stage, people leave their properties and undergo sufferings which cannot be measured in terms of money. Both the central and state governments have to spend huge sum of money for relief and rehabilitation of people affected by floods almost every year. Costly maintenance of roads, railways, structures such as bridges, barrages, intake works, river training works etc. are to be carried out regularly.

One of the most common causes of flooding is due to breaching of flood embankments in the plains. Repair of breaches and protection of flood embankments are very costly affair. In a hilly terrain, however, floods occur mainly due to extreme rainfall (cloud burst), melting of snow, land slides, glacial outbursts (GOLF) etc. A common cause of flooding in a hilly terrain is often due to change in river course (flow avulsion) mainly due to excessive sediment load causing shilting of existing channels and formation of new channels. This phenomena of river shifting from its existing course is common as the river comes to the foothill after its journey in the mountains.

Training of a river near bridges, barrages, flood embankments where river scour foundation and tend to outflank or breach the structures by construction of spurs, guide bunds, mattressing and revetment, construction of marginal /afflux embankments etc. is extremely costly and need regular maintenance. River training is necessary to control migration of meandering when it moves towards outer bank and silt up the inner bank. Poised rivers are few and most of the rivers are either aggrading or degrading or braiding or anabranching. River training is needed to control these formations so that a stable condition can be obtained.

All rivers originate in high altitudes and flow downwards with outfall in sea with zero elevation or in a lake or in another major river. The valley setting of rivers can be broadly subdivided into:

a) Mountainous or hilly region with very steep slope (1 in 5 to 1 in 100 approximately)

b) Sub-hilly or trough stage where slope reduces considerably (about 1 in 100 to 1 in 1000)

c) Flood plains with mild slope (about 1 in 1000 to 1in 10000)

d) Delta stage near its outfall into the sea (less than 1 in 10000 approximately)

Types of river training to be adopted are dependent on its valley setting. In the mountainous stage, the river has very high stream power – the product of discharge (Q) and bed slope (S_0). QS_0 gives stream power per unit width of stream per unit weight of water. With high stream power, the flow can easily carry boulders and gravels along the bed. In this stage, river flows in a narrow gorge and a number of small and medium streams join the river on the way. They are usually degrading (due to very high velocity) and carry sediments brought down from their catchments through formation of reels / nullies / gullies, land slides etc. Training measures in this stage, therefore, should be aimed at control of stream power thereby controlling erosion /slides through check dams, soil conservation in catchment areas. Prevention of toe erosion and consequent slides can be achieved by construction of short stone spurs or by gabion walls.

In the sub-hilly or trough stage, stream power is considerably reduced (due to reduction in bed slope, (S_0) resulting in deposition of boulders and gravels. In this aggrading stage, the channel through which streams flow get filled up with sediments and the stream starts flowing in a new channel. In this process, multiple channels are formed and the river goes on shifting its course resulting in delta like formation. Training a river in such an unstable braided stage of a river is extremely difficult and the river often destroys /outflanks the hydraulic structures like bridges/barrages/intakes and damages roads and railway embankments. Training works such as spurs, Guide bunds, revetments, cut-offs, dredging of sediments are found effective. Lining of channels improves conveyance of the river..

As the river descends into flood plains, the bed slope and stream power reduces further and even the finer fraction of sediments i.e. fine sand, silt etc get deposited on alternate banks resulting in meandering flow and formation of wide flood plain (also known as khadir or meandering belt) as shown in Fig.1.Because of the settlement of people in the fertile flood plain of a meandering river, flood embankments (also called levees, dykes, marginal bunds, flood embankments etc) are popular measures of river training for protection of people and their properties near river banks. Although constructed sufficiently away from river banks, these embankments are often subjected to river attack due to migration of meanders laterally. In all such vulnerable reaches, embankments are protected with revetment/ pitching / mattressing to arrest erosion of bed and bank and prevent breaching of embankments. Long / short spurs (both permeable and impermeable) are constructed to dampen / deflect the high velocity flow against direct attack by the meandering river. When hydraulic structures such as bridges / weirs / barrages are constructed in the wide khadir, its water way is often restricted with approach embankments (Fig.2) in order to reduce cost. Flow field which used to prevail before construction of such structures get altered after the construction. Regime of river is changed and new pattern of meanders develop both upstream and down stream of such structures. The river

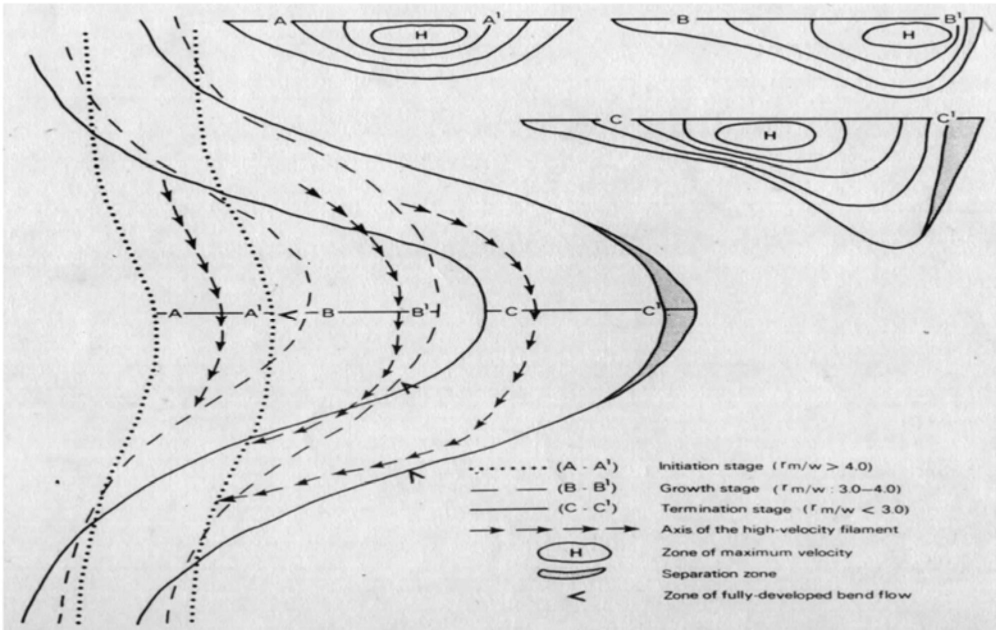

Fig. 1 Lateral Migration of a Meander and Stream cross Sections in a bend

(Taken from a paper by Mazumder-2001)

is in aggrading stage due to deposition of sediments upstream (due to afflux and back water), causing substantial loss of stream_power. Degradation occurs immediately down stream due to high velocity and residual kinetic energy of flow, higher turbulence and comparatively clear water flow.

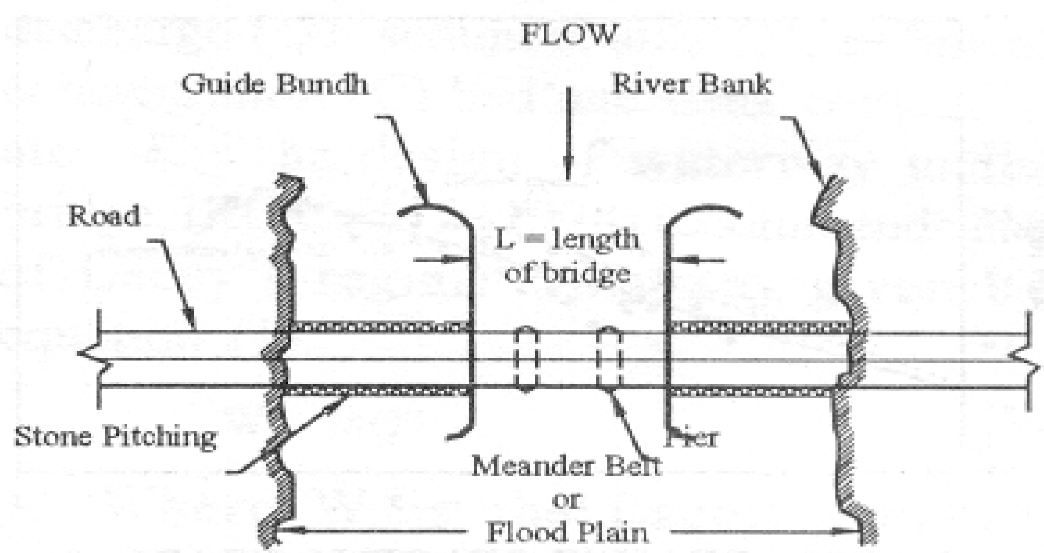

Fig. 2 Restriction of Waterway by Use of Guide Bund

(Taken from a paper by Mazumder et al,,2002)

One of the major evil effects of embankments and jacketing of a river is due to the fact that the country side looses the fines and fertile sediments which are deposited within the embankments thereby raising river bed level and lowering country level causing drainage congestion in the country side. In case of sudden breaches, there is wide spread and unprecedented flood damage (Fig.3a and 3b). Sometimes river changes its course rendering all hydraulic structures down stream useless and requiring new structures.

(Taken from a paper by Mazumder,2000)

Fig.3(a) Disastrous Flood in Malda District in West Bengal after Breach of Left Marginal Embankment Upstream of of Farakka Barrage, in the year 1998

(Taken from a paper by Mazumder,2011)

Fig. 3(b) Devastation brought about by river Kosi due to change of its course on August 18 th, 2008 due to Breach in its left Embankment about 12 km upstream of Kosi Barrage

As already mentioned, meanders move both laterally (at faster rate) and longitudinally (at slower rate) causing formation of wide flood plain (khadir) with shallow flow depth during lean season. Both permeable and impermeable Spurs are helpful in narrowing khadir width and increasing flow depth for navigability of river. Strong flow curvature in wildly meandering river can be controlled by cut-off which helps in straightening of the river and improving its navigability.

In _the final stage of its journey (before joining sea), the bed slope reduces to such an extent (1 in 10000 to 1 in 20000), that even the fine silts and clays transported by the river (as suspended load) get deposited forming deltaic islands e.g.Sunderbans, Mahanadi and Godavari deltas. Because of large volume of flood water and siltation, river divides and starts flowing in multiple channels. Distribution of flow in these channels alters periodically resulting in spill flow and damages to crops and habitats. Some of the rivers are also subjected to tidal effect. During high tides, rivers carry sea water and transport silt upstream. Training of rivers in the deltaic reaches consisting primarily of levees, groyens, bandalling, bottom panneling etc. are very popular. If it is a navigable river, maintaining minimum depth of flow for navigation (by constructing spur fields) is one of the objectives of river training in these reaches where the river widens and silts up.

2. NECESSITY AND OBJECTIVES OF RIVER TRAINING

River training is necessary for making better use of river and river water. An untrained and uncontrolled river may bring devastation due to flooding, change in course, braiding, meandering, scouring of bed and banks, breaching of embankments, damages of hydraulic structures, roads and railways etc. Different objectives of river training / river improvement are:

a) Control of floods due to overtopping (spilling) of natural banks.
b) Control of erosion / scouring and breaching of levees / natural banks.
c) Control of meandering and shifting of course, scouring, depositing etc.
d) Improving river geometry for increasing conveying capacity of both water and sediment flow
e) Improving navigability by reducing flow width and increasing flow depth.
f) Arrest local scour around hydraulic structures e.g. bridges, barrages, intakes, approach embankments etc.
g) Controlling aggradations, degradation and braiding of the river
h) Improving flow geometry to avoid oblique flow near hydraulic structures often causing outflanking of the structures.

Actually, every river has its individual and unique characteristics. The objective of river training and training measures to control it will, therefore, vary from river to river. It is essential to make an in depth study of the river behavior and morphology of the river before deciding the necessity and type of river training measures to be adopted in a particular case.

3. DIFFERENT TYPES OF RIVER TRAINING MEASURES

As already discussed under section -1, types of river training measures depend on its valley setting. Broadly, all river training works are engineering measures adopted to guide and stabilize the river in its own course without causing harm / damage to life and properties by controlling flow of water and sediments with a view to make best use of the river and river water. Different types of river training works in common use are briefly discussed in the following subsections:

3.1 River Embankments/ Levees/ Dykes

An embankment (also called levees and dykes) is constructed almost parallel to river bank and sometimes normal to the bank, (as in case of approach embankments in wide khadir, connecting hydraulic structure e.g. bridges and barrages) for the purpose of protecting adjacent lands and habitats from flooding due to overtopping and spilling of banks by flood water. They help in channelizing the river in a given course with adequate flow depth for navigation and reclamation of land. Further details about embankments / levees and their planning, layout and design criteria are given in IS: 12094.:2000

3.2 Revetments / Pitching / Rip-Rap / Mattressing

The most popular measure to prevent river bank erosion against high velocity of flow is to pave the river side banks / embankments with artificial revetments/ mattresses made of either loose and crated stone pitching laid over graded filters (or geosynthetic textiles) to prevent erosion of bed and bank materials. Articulated concrete blocks / brick blocks / asphalt concrete blocks, geosynthetic bags (filled with sand / debris) geo-tubes, geo-bags etc. are also used for lining. Further details about revetments, their sizes, thickness etc. are given in IS: 14262:1995

3.3 Spurs/ Groynes

Spurs / groynes - both permeable and impermeable types - are constructed transverse to the river bank and extend from bank / embankment into the river either at right angle to the bank (fending spurs) or inclined downstream (attracting spurs) or inclined upstream (deflecting spurs) with the objective of diverting high velocity flow away from the river bank. They also help in dampening of flow and encourage silting of the bank. They help in channelizing the river into a defined course in wide flood plains thereby reducing wild meandering, narrowing channel width and increasing flow depth for navigation purpose.

Impermeable spurs made of earth, fly-ash, debris, geo-bags, geo-tubes etc do not allow water to pass through the body of the spur and they deflect flow lines resulting in high concentration of flow near spur heads. It becomes very difficult to maintain the head of such spurs due to formation of deep scour holes near their heads, specially when the spurs are of long length. Very often, they are found to settle, crack and get washed out due to flow through the cracks.

Permeable spurs made of wooden or bamboo piles, porcupines, tetra hadrons, trees etc. permit water to flow through their bodies and are helpful in bank protection due to flow dampening and energy dissipation due to production of micro turbulence behind the spurs. Stone spurs made of either loose or crated stones allow some water to pass through their bodies initially. But eventually they behave like impervious type spurs due to trapping of sediments and debris. Low height stone spurs, also called bed bars, are submersible type, built at interval above reno -mattresses. They help in trapping of sediment and siltation of the bed and bank. Further details about planning, layout, design and maintenance of permeable and impermeable type spurs are covered in IS: 8408:1994, IS: 10751:1994, IS :14262:1995.Typical spur field used for river control in a bend is illustrated in Fig.4

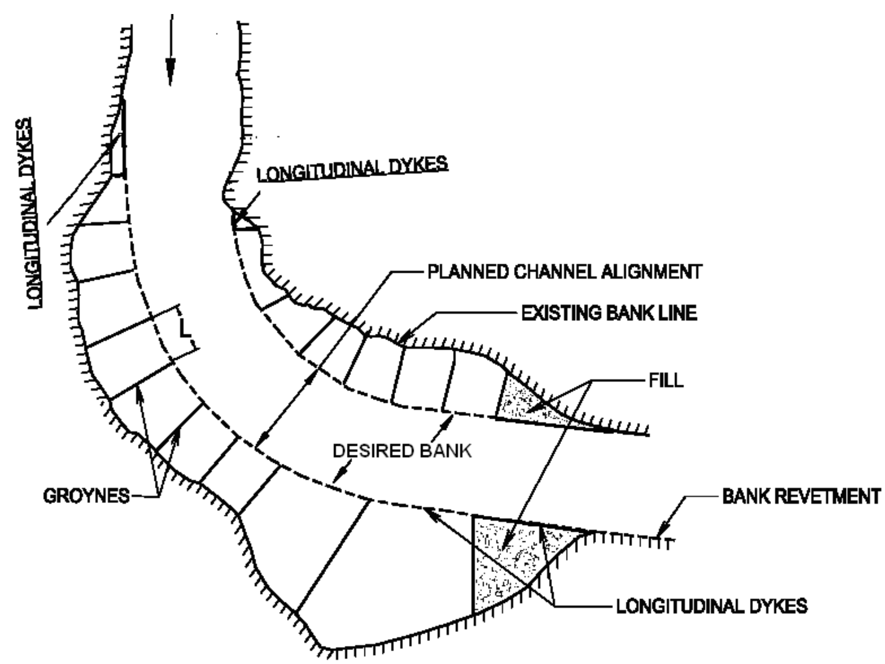

Fig.4 Showing Spur Field In River Bends For control of Erosion and River Navigability

3.4Guide Bunds

When bridges and barrages are constructed in the wide flood plain of a river, it is economical to constrict/restrict the flood plain width by providing a single or a pair of guide bunds and approach roads. Guide bunds (Fig.2) ensure that river flows parallel to piers and abutments and avoid any obliquity of flow near the bridge. They also protect the approach embankments on either side and prevent outflanking of the structure. Guide bunds are constructed of earthen dykes heavily protected with stone pitching / crated stone-gabions on the sloping face on river side and both faces near the head and tail ends. Launching aprons are also provided to protect the toe against scouring. Further details regarding planning, layout and design of guide bunds are given in IS 10751(1904).

3.5 Studs/Hard points

These are wide and short earth spur like structures to hold the bank lines. They are to be protected with stone pitching or crated stones against scouring of toe. They also help in controlling river alignment between two or more fixed points to avoid wild meandering of river near hydraulic structures.

3.6 Cut-offs

Meandering river has a tendency to shift laterally (Fig.1) on the outer bank side (concave side) with time due to secondary current which scour away material on the outer side of meandering bend and deposits the same on the inner (convex side) side of the bend. In this process, curvature of flow goes on increasing with time and the bend becomes sharper. Secondary current in the bend becomes stronger. As a result there is more scour and greater lateral shifting, The process continues till there is a formation of natural cut-off and formation ox-boe type lake. There is a lot of head losses in the consecutive sharp bends of a typical meandering river resulting in afflux and rise in high flood level (HFL). Sharp bends deteriorate the navigability of the river. Cut-offs – natural or artificial - help in straightening a river, fall in HFL and improvement in navigability of the river. Further details about cut-offs are available in CBIP publication "River Behavior, Management and Training", Vol.-.I (1989)

3.7 Meander Control Devices

One of the primary causes of river erosion is its meandering flow. As already stated, the outer side of a typical meandering bend goes on eroding whereas bar formation takes place due to silting on the inner bank. With increase in growth of the sand / silt bars, they advance towards the outer bank subjecting it to flow concentration and erosion. In this process river bends migrate laterally towards the outer bank side and sometimes take a new course or may join another nearby stream. Pitching / Mattressing / Spurs / Hard points / cut -offs etc. are constructed to arrest erosion of outer bank. Cement-soil grouting, gabion walls, vegetation growth are very effective means of controlling lateral erosion due to improvement of shear strength of the soil. Submerged type vanes developed by Odgaard(1986) and others are also found to be effective means of meander control. Further details of these vanes can be obtained from literature. Dredging of the sediment bars near their advancing / growing heads will also be highly effective for meander control by reducing flow curvature and controlling erosion of outer banks.

3.8 Grade Control Devices//Afforestation

In the hilly /sub-hilly terrain where the river flows in steep slope, erosion of river bed and banks causes serious problem of stability of the adjoining hills, resulting in slips and land slides. Grade control structures e.g. check dams, barrages, toe protection by wire crated stone gabions, etc are effective means of erosion control. The energy slope and the stream power reduce due to afflux created by these structures. However, flushing mechanisms /or manual removal of deposited sediments by dredging are necessary to make them effective. Hydro-power structures are highly effective for conversion of terrain head to generation of electricity through water turbines and generators by killing the stream power and reduction of sediment load in the river downstream and reducing land slides. Satellite imageries can be used to determine land use and to find sediment yield index of catchment soils and delineate erosion prone areas for planning afforestaion. in the catchment areas.

3.9 Bandalling

In the delta stage of a river, it starts flowing through a number of channels. Sometimes, the flow through main channel reduces due to shift of flow through adjoining tributaries resulting in reduction in flow depth in the main channel. As the stream power reduces further (due to reduced flow in main channel), the main channel tends to silt up. To improve the navigation facility in the main channel, Bandalling is an effective device. Inclined vanes are installed at inclination to divert the flow from the subsidiary stream to main stream and a favorable streamline curvature is developed artificially for diverting silts away from the main channel towards its offshoot.

3.10 Pitched Island

As already mentioned earlier, many rivers are found to form a number of silty / sandy island (also called chars) upstream of hydraulic structures like bridges and barrages. When such chars form centrally, the river divides into two or more channels (anabranching). In the lean off flood season, the river flow occurs through these branches. Usually, the branches near the banks are found to carry more flow subjecting it to erosion, due to formation of secondary currents in these curved channels with their outer bend towards the bank. River tends to outflank the structure by breaching the approach road./ flood embankment. Central islands can be so curved and pitched (or provided with artificial cut-off) that the flow will tend to move away from the outer bank and forced to flow centrally normal to the hydraulic structure, thereby improving stability and reducing the risk of outflanking.

4.0 SELECTION CRITERIA FOR RIVER TRAINING WORKS

Unlike a structural or a foundation engineer who knows the various modes of failure and is equipped with thorough knowledge of materials for the evaluation of stress, strain, deformation, settlement etc., a river engineer in charge of river training hardly posses any information with scanty or sketchy data available from the site. Time available is also very limited for thorough analysis and he has to take quick decision regarding the measures to be adopted to avoid failure due to erosion or other reasons. Any wrong decision may be totally ineffective and being very costly the money spent will . virtually be wasted due to washing out of the wrong protective measures._In such a circumstances, experience of the river engineer is of paramount importance. In the past, a number eminent river engineers like Chitale(1981), Khosla(1953), Gole(1966), Gulhati, Garde et al (2000)from India and Lacey, Lane, Blench, Bell, Spring, Gales et al from abroad have successfully planned and implemented river training measures which have been successful over time. Using floats and observing movement of debris and other floating materials, they had been trying to understand the river behavior. In important structures, Model study should be carried out to find the areas likely to be eroded or silted up by observing flow lines, velocity distribution, flow concentration etc and decide about the type of river training measure to be adopted in a given situation.

The subject 'River mechanics and engineering' has developed over the years due to immense contribution made by Lane,(1955) Blench,(1957) Hickins, (1984) Oddgard(1986), Breussers,(1991) Kennedy(1969), Raudkivi (1976), Diplus et al from abroad and Garde(2006), Rangaraju (2000), Mittal, Chitale(1989), Kothyari(1957) et al from India. River behavior is intimately related to both flow of water and sediments. Over the decades, there is a lot of development in both hydrology and hydraulics of sediment transport, which are discussed at length in the CBIP publication 'River Behavior, Management and Training'..

Besides experience, river engineers must have sufficient knowledge of the subjects e.g.hydrology, hydraulics, river morphology, river mechanics, sediment transport and fluvial stream processes to understand the river behavior. Every river has its history and possessing historical data of the river behavior in the past, apart from present data, e.g. river section, bed profile, plan view, flow of water and sediments,HFL in the river and their variation with time, valley setting, , nature of river bed and bank materials, catchment characteristics etc are essentially needed for selection of type of river training measure. Valuable information to be collected both from near field and far field of a river in the vicinity of hydraulic structures like bridges, barrages, intake works, flood protection and river training etc will be of great help in the evaluation and decision making regarding types of training measures to be adopted / selected in a given situation. It should be remembered that no general solution can be recommended since the problems are unique and river specific as almost all rivers have their unique behavior.

Before recommending some broad guidelines regarding selection criteria, it will be worthwhile to go through some important aspects of river behavior since most of the river training measures are dependent on river behavior in the vicinity of affected areas..

5.0 RIVER BEHAVIOR IN THE VICINITY OF AFFECTED AREAS

Proper understanding of river behavior in the vicinity of affected areas/structures is extremely important for planning, design and layout of river training works for their safety. Flow field, which used to prevail prior to their construction is often changed. There is afflux subjecting the channel to backwater effect upstream. Hydraulic and energy gradients are decreased resulting in loss of stream power and deposition of sediments upstream of the structure. On the downstream side, there is generally degradation near the sructures due to low sediment content, residual kinetic energy of flow and higher turbulence level. Uncontrolled aggradations/degradation causes a lot of problem. The river tries to widen and outflank the structures. Costly protection measures are to be adopted to make the river flow axially through the structures. Depending upon the amount of restriction, the approaching flow may often become unsymmetrical and unstable. Such river may shift their location and may wander anywhere within the wide valley/ flood plain (khadir) resulting in erosion of both bed and banks of the river. It may also breach/ washout the protection works.

5.1 River Morphology/ Aggradations/ Degradation

Understanding of river behavior is complicated due to integrated geo-morphologic, hydrologic, hydraulic and sediment parameters. Inter relation between river plan form, hydrologic, hydraulic and sediment parameters and relative stability of the river is illustrated in Fig.5. It may be observed that the different plan forms i.e. straight, meandering, braided etc. depend on the river geometry, sediment load, slope and flow in the river.Quantitative prediction of river response due to climatological and watershed change is based on the fundamental relation given by Lane(1957) and Brown Einstein(1942)

Lane's Theory: $QS_e \ \alpha \ Q_S \ d_{50}$

Brown-Einstein's Theory: $q_sS_s \ \alpha \ q^2 \ S_0^2/d_{50}^{1.5}$

Where Q is the flow rate,q is the discharge per unit width(discharge intensity) S_e is the energy gradient, Q_s is the total sediment transport rate, q_s is the sediment load transport per unit width (sediment discharge intensity)and d_{50} is the mean size of sediments being transported and S_s is the specific gravity ofsediments. Fig 6 illustrates the regime diagram given by Lane for quantitative prediction of river regime.

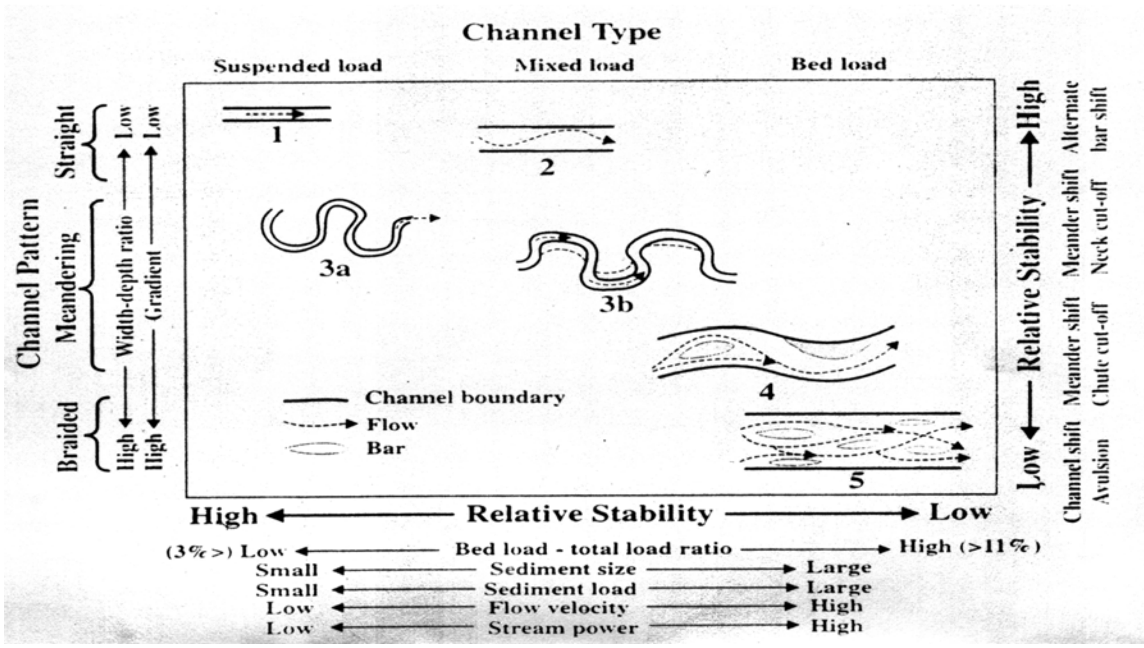

Fig. 5 **Interrelation between Channel type, Hydraulic and Sediment Parameters and Relative Stability of Streams**

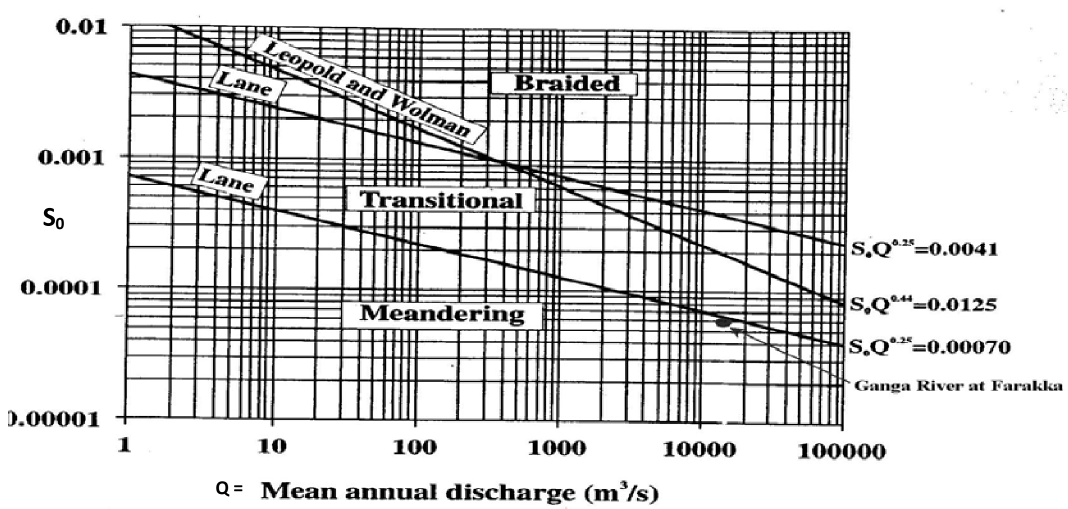

Fig. 6 **Prediction of River Regime from Bed Slope and Mean Discharge**

5.2 Change in River Regime due to Human Interference

Aggradations / degradation near hydraulic structures is mainly due to the loss in balance between sediment supply and transport rates. Rivers attain a stable regime over hundreds of years through adjustments of its slope and section according to volume of water and sediments carried by it. Many gifted river engineers like Lacey(1930), Blench(1957), Lane(1955), Diplus(1990) from abroad and Garde(2006), Rangaraju(2000) Chitale(1981) from India have done considerable work to predict the regime state and corresponding river geometry based on sediment size in river bed and bank and the dominant discharge carried by the river over time.

The major cause of change in river regime can be attributed to human activities and interference. Regardless of degree of stability, human activities can produce dramatic change in river regime locally and throughout the entire river. River improvement works by man made river structures can often result in departure from the equilibrium stage that existed prior to construction of these works. The challenge to the river engineer is to understand the hydroogic, hydraulic and geomorphologic balances within a given waterway and the catchments and to design the project within the framework of these balances. Such an approach will generally prove to be more efficient than continually trying to maintain the system against the natural tendencies. River regime is affected by high afflux, deposition of sediments scouring, flow instability, meandering, bank erosion, outflanking, flooding etc.

5.3 River Stability and Meandering

Inter relation between stream form and bed slope is shown in Fig 5. According to Lane(1955), a river with non- cohesive bed and bank material is predicted to meander if

$$S_0 \ Q^{0.25} > 0.00070$$

and braided if

$$S_0 \ Q^{0.25} > 0.0041$$

A typical straight river is rarely stable. As shown in Fig.5 , rivers with very small flow of water and sediments, low gradient and velocity, low aspect ratio (Bed width to depth ratio) may be more stable for some distance. Development of lateral instability associated with erosion and deposition on alternate banks give rise to thalweg pattern. Uncontrolled erosion and deposition ultimately give rise to typical meandering pattern.

Hickin and Nanson (1984) described the lateral migration rate (M) of a meander by the functional relation

$$M = f(\Omega, b, g_s, h, \zeta_b)$$

Where Ω is stream power, b is a geometric parameter of the river such as width of the river, h is height of outer bank, g_s is sediment transport rate, ζ_b is the erosion resistance offered by the outer bank against erosion. Plotting measured migration rate M (in meter per year) against relative curvature (r/w) (where r is the radius of curvature of flow lines and w is width of stream), Hickins(1984)) concluded that migration rate is maximum when r/w = 2.5 (fig.7).He derived the relation for maximum migration rate $M_{2.5}$ (in m/year).as:

$$M_{2.5} = \rho g Q S_o / \zeta_b h$$

Where ρ is density of water in kg/m^3, g is acceleration due to gravity in m/s^2, Q is the mean flow rate (in m^3/s), S_o is river bed slope, ζ_b is bed shear stress in kg/m^2, h is height of outer bank in m. Fig.1 illustrates the typical development of a meander and migration of meander.

5.4 Analysis of Flow in the Vicinity of Hydraulic Structures

Depending on afflux and normal flow depth , the flow both upstream and downstream of a hydraulic structure e.g. bridge or barrage has high non-uniformity (Fig.7) and often found to swing periodically either to the left or right bank (usually main channel flow adheres to either left or right bank) due to their instability. It behaves like a highly turbulent wall jet type flow. Deposition of sediments occur leading to aggradations due to back water effect and loss of stream power upstream. Cross slope develops (because of deposition of sediments on inner bank and scouring on outer bank as shown in Fig.1) resulting in meandering of the river. Immediately downstream of the structure, there is degradation (due to oblique jumps and roller formation, often observed with choking flow condition. turbulent flow with comparatively clear water (due to sediment deposition upstream) often with choking flow condition flowing downstream with higher turbulence level is also responsible for general degradation immediately downstream of hydraulic structures.

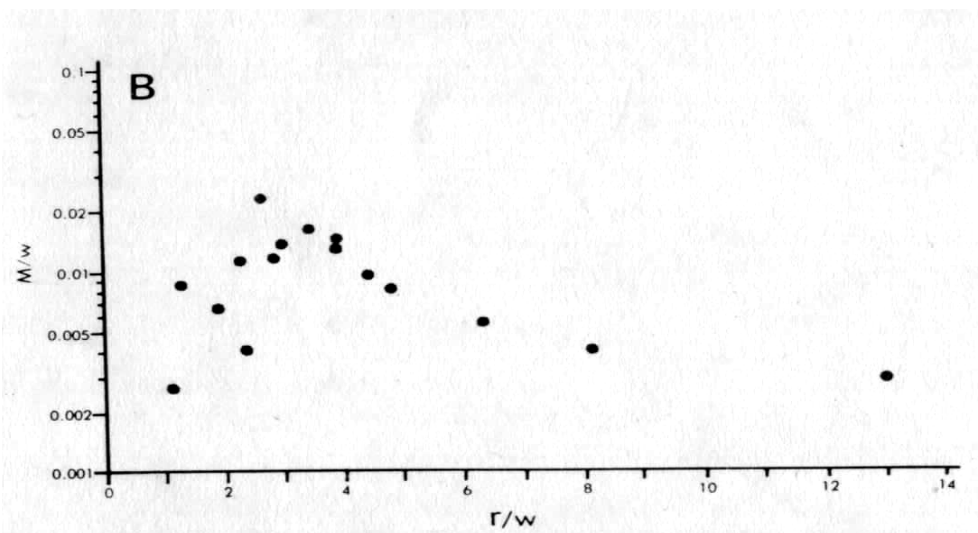

Fig. 7 Variation of Migration Rate (M) with Relative Curvature (r/w) in a Meander

In the case of barrages where there is flow diversion, discharge in the river decreases downstream. Bed slope (S_0) also reduces resulting in loss of stream power i.e. QS_o. As a result, the sediment carrying capacity (Q_s) has to reduce downstream (unless new tributaries join) for to satisfy Lane's equation

$$QS_o \;\; \alpha \; Q_S \, d_{50}$$

Thus, in such a situation (with flow diversion), the river will undergo aggradations downstream (after the degrading zone) with time. In a wide Khadir (as observed in most of the rivers in north and north-east India), when there is high amount of constriction of normal flow width (Fig 2), there is aggradations. upstream of hydraulic structures. Such aggradations often result in formation of multiple channels and the main channel flowing along the bank causes scouring. Sometimes, the flow becomes unstable due to long spurs constructed across main channel as a protective measure Long spurs (designed on the basis of total flood plain / khadir width) may constrict the main channel flow to such an extent, that the flow in the main channel may become unstable and it may swing and directly attack the bank in between consecutive spurs resulting in breaches in embankments and wasting out of the spurs, guide bunds and may outflank the structure. Flow non-uniformity is responsible for meandering, cross-slope and deep scour near banks where the main flow is adhered to. Fig.8-10 illustrate few typical cases of outflanking, meandering and anabranching of flow near some bridges on major and minor rivers in flood plains

Deep erosion occurred near left bank of Ganga river (with its main channel flowing along left bank) upstream of Farrakka barrage. When all the spurs were washed out. Porcupines were constructed to save left bank subjected to colossal erosion and shifting of river 7 km inside the fertile land of Malda district in West Bengal. Figs. 3(a) shows the disastrous flood in Malda district In West Bengal after breach of marginal embankment about 20 km upstream of Farakka Barrage, Fig.3(b) illustrates the devastation brought about by river Kosi due to change of its course on August 18 th, 2008 due to breach of its left embankment about 12 km upstream of Kosi Barrage. Kosi river is had been laterally shifting its course by as much as 120km in course of 100 years before jacketing the river with flood embankments.

6.0 CHOICE OF RIVER TRAINING MEASURES

As already stated under section 4.0, choice of a particular type of river training measure will largely be river specific and will depend mostly on the river behavior. A brief discussion is made in the following sub-clauses as a guideline for selection of river training measures.

6.1 Flood embankment / Levees / Dykes / Afflux and Marginal Embankments.

When a river is found to often spill it**s** bank / banks causing damage to life and properties in adjoining areas, obvious choice is flood embankment to contain the flood at design discharge and design HFL Levees are constructed away from bank / banks / khadir on high ground to physically obstruct the flow of water and sediments towards the countryside. When there is high afflux due to construction of hydraulic structures, embankments (also known as afflux / marginal bunds) are made with its top level above the affluxed HFL in the entire reach of backwater upstream of the structure.

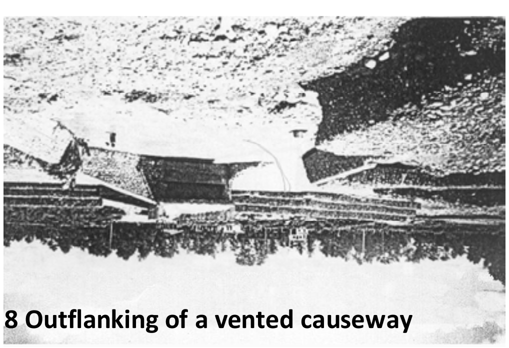

Fig. 8 Outflanking of a vented causeway

(Taken from Mazumder,2005)

Fig. 9 Erosion on Right Bank of MahanandaRiver Showing Embayment U/S of the Bridge on NH-31

(Taken from Paper by Mazumder,2010)

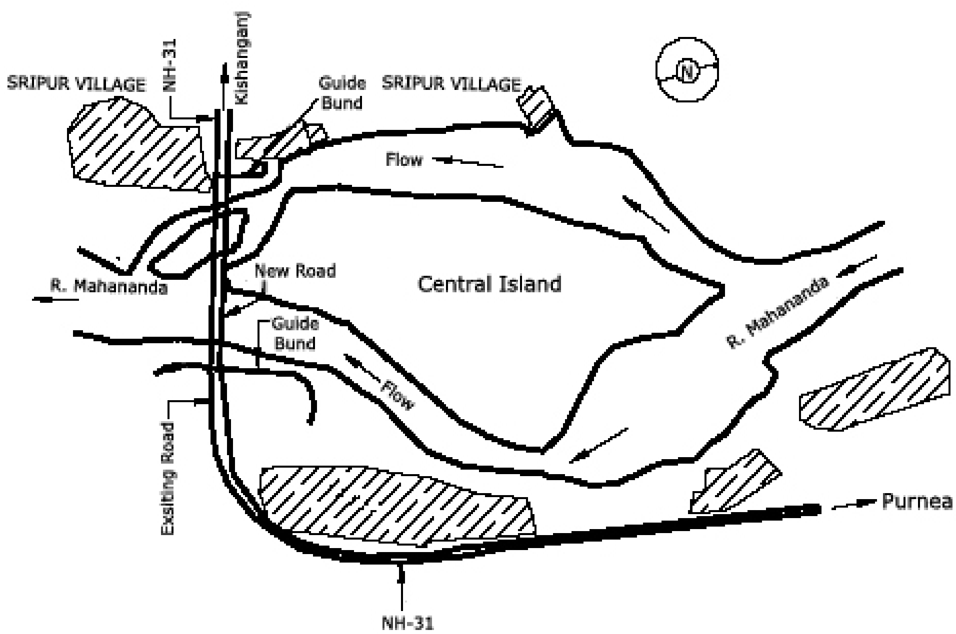

Fig. 10 Plan showing Anabranching of River Mahananda u/s of Bridge on NH-31

(taken from paper by Mazumder,2010)

6.2 Pitching / Rip-rap / Revetments / Mattresses/ Lining

These are artificial lining of stones / crated stones / concrete or masonary lining to prevent erosion of riverbanks due to high velocity of flow. Although embankments are made away from bank, a braided and meandering river scour away the soil in khadir and at places flow near embankment. Stone pitching of appropriate size and proper weight have to be provided in order to prevent failure / breaching of embankments. Launching apron or mattresses are required to protect the toe of banks and embankments to avoid outflanking, sliding, cracking and breaching of embankments. All such linings reduce roughness and increase carrying capacity of water and sediment flow resulting in river improvement. They must be laid over a continuous layer of graded filter or geo-synthetic textiles or jute geo-textile to prevent winnowing of fine bed materials. Otherwise, they will sink, settle and get washed out.

6.2 Spurs / Groynes

Whenever the flow is skewed near hydraulic structures (not normal to river axis) due to meandering, braiding, or any other reasons, the flow will attack the bank / banks and subject it to damage/ breaching. Spurs and groynes *were* are useful devices to deflect the high velocity current away from the bank. Series of spurs (Spur Field) are constructed to control meandering and appropriate river alignment for improving navigation and flood control They tend to straighten the river and reduce tortuisity of an uncontrolled / untrained river. Suitably located spurs near hydraulic structures / approach embankments are very useful in preventing outflanking of structures and breaching of approach embankments. Unsubmerged earthen spurs (also known as groynes) help to protect flood embankment. Submerged stone spurs / porcupines / pile spurs etc. are, however, constructed for river improvement in meandering / braided channels. They are efficient too and not susceptible to damage like earthen spur which are impervious and there is high degree of flow concentration near the head of spurs resulting in damage to their heads. Permeable spurs like porcupines / pile spurs / tetrahedrons / geotubes / geosynthetic sand bags/ tree spurs etc., on the other hand, are pervious. They permit the water to flow through their bodies resulting in very little or no flow concentration. All the spurs - permeable or impermeable - are to be protected with stone pitching laid over graded filter / geosynthetics, except geo-tubes and..geo-bags which are made of geo-synthetic materials (filled with sand and debris) acting as filter

6.4 Guide Bunds

When a hydraulic structure like a bridge or a barrage is to be constructed on a wide flood plain, river will tend to flow oblique to the structure (even if constructed symmetrical to the khadir) due to continuous shift of main channel of the approach flow. In such situations, the structures are in danger due to river attack on piers, abutments, approach embankment, spurs etc. Guide bunds, originally invented by Bell and subsequetly improved by Spring and Gales, are very efficient device to reduce the damage, by smoothly guiding the flow so that it approaches and departs the structure axially i.e. normal to the structure without any flow obliquity near the structure.

6.5 Misc. Other R/T works

Detailed discussions have already been made regarding other miscellaneous. river training measures e.g. studs, cut-offs, meander control devices, grade control devices, bandalling, pitched islands under sections 3.5, 3.6, 3.7, 3.8, 3.9, 3.10 respectively. Table to be used and underlying principles of their action. Planning, layout and design criteria of river training works have been discussed under sections 3.1 to 3.4 in relevant IS/IRC/RDSO codes.

7.0 TRAINING RIVER MANDAKINI FOR PROTECTION OF KEDARNATH TEMPLE & TOWN

The Kedarnath town was virtually washed out due to flash floods in the river Mandakini and Saraswati which joins Mandakini river after Kedarnath town. Fig.11 shows the devastations of the township after the flash flood. It is reported that during 15-16 June night a wall of water about 4m high descended to the Kedar valley from the adjoining hills accompanied with large size boulders and debris moving with very high velocity. The impact was so sudden and so high that about 700 people died and most the buildings including the sacred Samadhi of his high holiness Sri Adi Shankaracharya, (the great Hindu monk who saved Hinduism from spread of Budhism in India), were washed out. Such kind of flash flood lasting for a short period is not possible due to normal flooding in a river and it must be due to the overtopping of ChorabariTal, thereby breaching the fragile morain banks of the Tal and consequent change in the original Mandakini river course upstream of Kedarnath dham as depicted in Figures……, in clause- E of section-8 of the report. Section-4 explains in detail the cause of flash flood.

Fig.11 A view of the washed off buildings in Kedarnath Dham in Uttarakhand following incessant rains and floods. (PTI photo). Kedarnath Temple can be seen in the photograph.

7.1 About Mandakini River and Destructions In Kedarnath Valley

A tributary of river Ganga ,Mandakini river isriginates in the western Himalayas at an elevation of about 4,800m. It joins with river Saraswati just downstream of Kedarnath valley, river Alkananda near Rudraprayag and river Bhagirathi (name of Ganga.upstream) near Devaprayag (Fig.12).Mandakini. river has a catchment area of about 45 sq. km up to Kedarnath valley at an elevation of about 2500m. The catcment area is mostly covered with snow and glaciers with almost bare land without any vegetation. In the month of June, the snowline moves up to an elevation of about 3000m with little rainfed area. Run-off occurs principally from snowmelt due to higher temperature and heavy precipitation in the catchment in the month of June. The river has very high longitudinal bed slope upstream of Kedarnath valley when it falls through a height of about 2300m (4800m-2500m) in a length of about 10km only, resulting in a slope varying from 1 in 4 to 1in 5. As shown in Fig…, Mandakini used to flow on the west side of Kedarnath valley before joining river Saraswati flowing on the east side of Kedarnath. After the flash flood during 15-16 June,2013, the river suddenly abandoned its old course and started flowing eastward in an old abandoned course and joined Saraswati river just upstream of the Kedarnath valley, capturing all the minor streams in between rivers Mandakini and Saraswati on its new course. The old course of the river is completely choked with debris and stones with little conveying capacity of the river in the valley region. Flash flood due to breaching of Chorabari Tal and the combined flow of water, sediments and debris in the new Mandakini and Saraswati coming upstream of the Kedarnath valley brought devastation of the valley causing loss of life and properties during 15-16 June,2013 night. Excessively high stream power of the river due to very steep slope, capturing all the intermediate streams in the catchment and breaching of Chorabari Tal are responsible for the destructions brought about in the Kedarnath valley.

7.2River Training for Protection of Kedarnath Valley

Kedarnath being one of the holiest pilgrimages for the Hindus must be rebuilt and connected with roads/foot tracks etc. for communication and offering puja to Lord Shiva in the Kedarnath temple built by Adi Shankacharya in 8th century BC. Before the huge investments to be made for reconstruction, it is to ensured that there is no such destructions in future by the river Mandakini and its tributories. The protection works should be grouped in to two categories, namely short term immediate measures and long term measures as follows:

7.2.1 Short term measures

Any attempt to bring back the river in its old course by removing the stones and clearing the debris (except for the movement of people) may be futile since river diversion from its new course to the old course without construction of regulating structures may be impossible. Moreover, the new course of the river appears to be more stable due to formation of meander upstream. However, it is to be ensured that the new course has sufficient capacity to convey the flow of water and sediments during such flash floods in the rivers. Short term measure may also include building a protective marginal embankment/levee of adequate height and foundation around the complex strengthened by adequate numbers of stone spurs and revetment to be designed to resist impact of similar flash floods.

7.2.2 Long term measures

Long term measures may comprise of the following

(a) Reduction of stream power by constructing check dams in the steep stretch of the river/s
(b) Prevention of slope failure in the adjoining mountains by construction of wire crated stone gabions to arrest toe erosion and other techniques like rock bolting, strengthening of soil/rock by use of soil reinforcements, proper drainage arrangement etc.
(c) Soil conservation measures in the catchment areas by construction of check dams, contour bunding, suitable plantation etc.
(d) Construction of dams in the Chorabari Tal area or other suitable areas in the catchment for interception of flood water and sediments and diverting the flow through tunnels for utilizing terrain head in hydro-power generation, release of flood flow through stepped type chute spillways with energy dissipation arrangement at the toe of spillway to dissipate residual kinetic energy of flow.

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