

Geo-textile in Riverbank-Embankment Protection from Flood Flow Erosion

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Conflict: Nothing

Contribution: First and corresponding address dominates in hydrological and hydraulic studies, while the co-author's study dominates in material application and model testing.

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ABSTRACT: Bank erosion of rivers, e.g. Bagmati, Burhi Gandak, Kosi and Kamla-Balan, all originating in the Himalayan hills of Nepal and flowing through the alluvial plains of North Bihar, is a chronic and common phenomenon. Cutting and deposition result in shifting or meandering of the river endangering the embankment, road, bridge, barrage, and countryside. Anti-erosion and maintenance require huge investment. The river Kamla-Balan faces bank erosion throughout its embanked length, but stretches at km 37 and 62 are highly unstable and vulnerable. This paper deals with the problem, presents the hydrological details responsible for the hazard, and demonstrates the effectiveness of supplementary geo-textile with conventional sand filter pitching to protect the soil and slope of the riverbank. Estimated flood discharge and velocity at 100 years of return period is nearly 2100 cumecs and 0.9 m/sec, respectively. Riverbed and bank material is represented by silt with d_{50} of 0.018 to 0.05 mm while 0.02 mm of silt may get eroded and transported by river flow above 0.15 m/s. Launching apron is also required due to local scour. Model study test shows its suitability under various hydraulic conditions. Study reveals the effectiveness of woven type geo-textile reinforced revetment irrespective of cost and environmental consideration.

Keywords: Kamala Balan; Scour depth; Geo-textile; Revetment; Hydrology & hydraulics.

1. Introduction

Erosion of riverbanks and riverbeds is the major geo-engineering problem for the safety and life of the hydraulic structures constructed to contain, pass, or regulate the flood or supercritical flow. Mishra (2010) ^[1] having long experience to realize that an outsider Noble Laureate was more handicapped than any officials of the Govt. in the matter of resources to provide any flood disaster solution. Member officiating National Disaster Management Authority desired from the conference of National Hydrology Project to evolve various technological solutions for preventing or reducing the losses due to disasters, which seems challenging year after year and fails to deliberate ^[2]. Flood hazard related database and inventory web application deploying Embankment Asset Management System for Kosi basin (K-EAMS) online is yet to be realised that it is solution and action or crisis ^[3].

This problem of soil erosion exists in all types of geological, geographical, or geomorphologic base of river system. The solution is technical, but a site-specific action is more effective than a general one. In order to maintain the embankments in position, large-scale anti-erosion works in the form of spur, and revetments are required before the flood season at vulnerable locations. Large chunk of the budget goes into the erosion control works. Bihar is the top most flood-prone state of the nation and has a series of continuous or discrete embankments facing erosion, overtopping, cutting or breaches at 63 places in 2004 ^[4]. Even in normal flood years, 2005 & 2006 reported embankments breach at 8 and 1 places, mostly in North Bihar, Kamala Balan occupied 7 and 1 places, respectively. Health and safety of the embankment remain under question, whatever may be justification (unprecedented rain, flood or cutting by villagers and anti-socials). Floods in Bihar result in significant human and financial losses annually. Prevention of erosion suggested was with boulder and sand filled cement bags ^[5]. Amid recent anti-erosion practices using boulders and sand filled cement bags for flood issues in North Bihar ^[6] and works in progress during the period of COVID19 ^[7] floods are playing their devastating role ^[8] (Figure 1).

Geo-textile is a genetic term, which includes geo-synthetics, geo-membrane, geo-grids, geo-nets etc. Geo-textiles fall into five categories as per their fabrication, i.e. woven, heat-bonded non-woven, punched non-woven, knitted and fibre/soil mixing. Although geo-textiles use started during 1960s-70s for a variety of applications, i.e

filtration, slope stabilisation and drainage, use of these materials to control soil erosion on steep slopes were realized in 1992 ^[9]. Riverbank protection in 1992 using 600 m² of Coir (geo-textile) in Chowara near Alwaye was encouraging and 575 geo-textile bags were used in 2001 for controlling sea-beach erosion at Chellanam. Material durability



Figure 1. Flood and Anti-erosion works (a) after Singh (2010) ^[6], and (b) during lockdown in Bihar April 2020) ^[7], and (c) breach in Kamala Balan embankment near Jhanjharpur in July 2019 ^[8].

and performance also matters, as jute losses its tensile strength within six weeks, while Coir losses only 20% of its tensile strength even after one year in water and its tensile strength remain unchanged for 8 to 10 years under seashore water conditions ^[10]. Both, Jute and Coir are available in Nepal and India.

Conventional techniques and materials in use were not found enough durable in order to control riverbank/embankment erosion/cutting. The revetment section, designed with a layer of geo-textiles may prove durable and cost-effective over the years. The main objective of the study is to study and investigate the possibilities of geo-textile material to use to protect a typically historical cutting and erosion stressed riverbank and embankment location under the hydrological and hydraulic conditions of the River Kamala Balan flood flow.

2. Study Area

Flooding and bank erosion of rivers Burhi Gandak, Kosi and its tributaries Baghmati cum Kamla-Balan are known historically ^[11-14]. The river Kamla-Balan has its own history of shifting river courses and bank erosion since 1893 due to devastating flood. Although, the damages due to floods in years 1938 to 1941 and 1956 to 1959 are remarkable, Left and right banks embankment (total 160 km) of the river Kamla-Balan, constructed in 1964 to regulate flood flow water, starts from Indo-Nepal border near Jainagar in the state of Bihar and left open after Kothram before joining the river Bagmati or Kosi. During flood season people of villages lying in between and outside the embankments, have to take shelter on the embankment. Although the problem was activated exponentially after construction of embankment mainly due to rise in the bed level and velocity of floodwater.

Kamala Balan upper catchment area of 1963 km² (35%) falls in Nepal while lower 3600 km² (65%) falls in North Bihar of India. Lengthwise this river traverses nearly 72 km (22%) in Nepal and 256 km (78%) in India from a lofty hill slope to an alluvial plain ^[15-16]. About 95% of its flood plain area has 196 km of embankment. Floodwater of 1.2 to 0.1 m/s velocity varies in stretches. Embankment from Jainagar (Indo-Nepal boarder) to Kothram in right 95.5 km and in left 92 km (total 187.5 km) has a gap from 12.5 to 22.5 km in left ^[17]. Damages due to flood of 1974, 1975, 1978, 1985, 1987, 2004, 2007, (2000-2008) and until now are memorable in which affected area ranged between 2 and 4 lakh ha, against an average of 0.6 lakh ha. The high silt

concentration (1.725 gm/litre) and the nature of aggradations and degradation at stretches are alarming. The most vulnerable points near the village Kanhauli, Bhakuwa, Banuar, Sukki, Devera, Thenga, Maharajpur and Bhatgama etc. of western embankment as well as a few points near village Bugras, Bhaduar, Pipraght, Bridge and Asma of eastern embankment are not in a position to face devastating stroke of floodwater.

As consequences of heavy rainfall in Nepal during 1-2 August 1993, the river Kamla Balan virtually changed its course spilling out 70% of its flood flow at 53.7 km of right embankment near Sohrai inundating Alinagar, Ghanshyampur and Manigachi blocks in Darbhanga district due to widening-up of the breach up to 250 m ^[18]. After 25 years status are not satisfactory as Kamala Balan western embankment breached near villages Naruar and Ramkhetari, while eastern embankment near village Rakhwari of Jhanjharpur block/Subdivision. People of hundred villages from 10 blocks out of 21 blocks got affected ^[8]. Although raising, strengthening and protection works of embankment had taken place covering 33.7 and 27.81 km in 2018 on the left and right banks, respectively at critical reaches of Kamala Balan ^[19].

The river sections, at 37 km near the village Banuar and at 62 km near the village Devera of western embankment found critical to study the nature of erosion and possible control measures in 1993. Interview conducted with the concerned officials as well as locals and collected specific information, soil and water samples. Figure 2 shows an index map of the study area. Figure 3 and Figure 4 show the details and sections of the study zones at km 37 and 62 km of the river Kamala Balan right bank embankment.

3. Methodology

To control erosion, it is necessary to know the relation between particle size and density of the soil or material in use, the velocity of the flowing water or the shear stress exerted by the current. Different types of revetment have been applied in river regulation works depending upon the cost and availability of the local material. It is important to make a distinction between permeable and impermeable revetments. The most common example of the permeable revetment applicable in the dry as well as underwater conditions is the dumping of stones, which forms more or less a graded layer on the erodible silt-base. The designed thickness of such a layer must be large enough in case of fine silt-base, as a strong turbulent and fluctuating current may suck the silt through the pores between the stones. Under such situation, a layer of Geo-textile as a filter media may prove more

reliable material for riverbank protection, if not for bed, as an erosion control measure. Geo-textile has been placed between the Rip-Rap and soil of the slope of the embankment to prevent the migration of fine soil particles by velocity of water and wave action of water flow which causes the soil erosion.

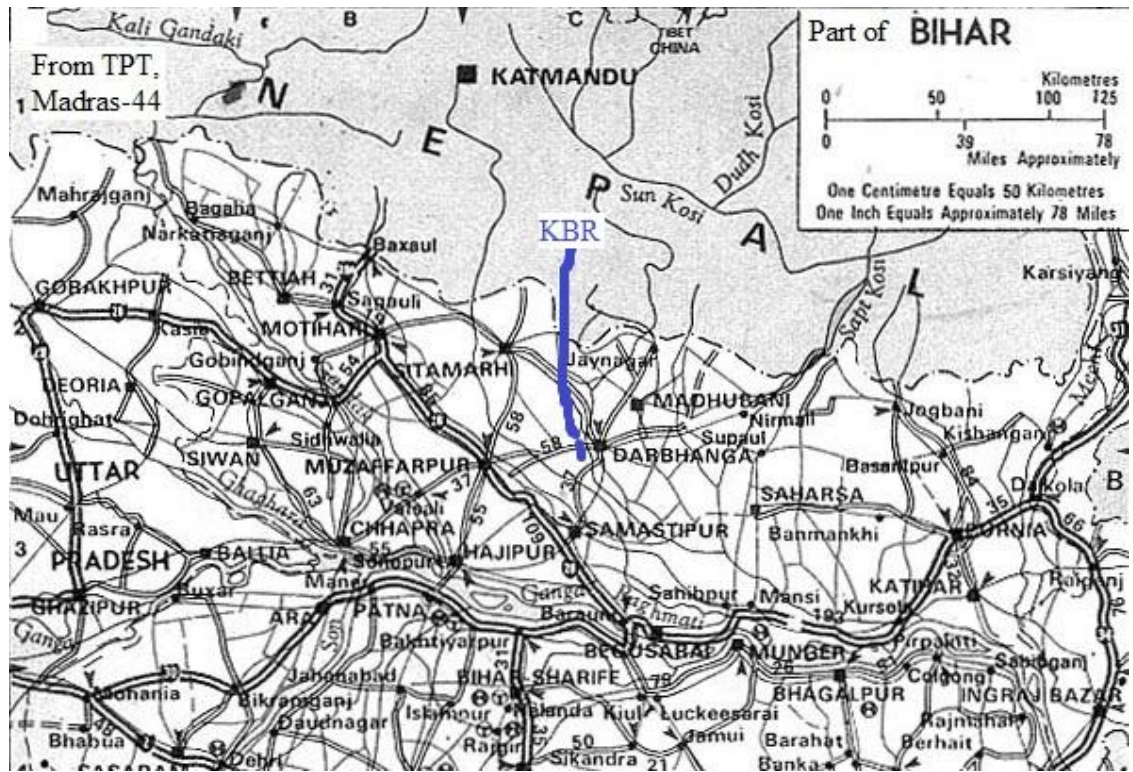


Figure 2. Index map showing study region in flood affected part of the Bihar in India indicating location of Kamala Balan River ^[20].

Therefore, we selected a pair of typical and badly affected embankment stretches during 1990s by the flood flow in North Bihar ^[21] and study carried out. Consequently, hydrological and hydraulic analysis (soil particle size distribution, flood discharge at HFL, flow velocity, scour depth, etc.) have been performed including designed application arrangement to augment the cutting and erosion control measures of slopes, sides and toe of the embankment. Subsequently, having details of two most vulnerable stretches/sections, suitability of supplementary geo-textile material has been studied and tested in laboratory and a model test conducted by the co-author to verify the efficiency and effectiveness of geo-textile layer.

We used information available through literatures and Water Resources Dept, Govt. of Bihar ^[21]. The stage, discharge and HFL at Jaynagar and Jhanjharpur sites of

Central Water Commission were helpful in frequency analysis of flood flow stage and discharge. The flood flow velocity and discharge at HFL estimation performed using conventional Slope-Area method and scour depth has been determined for the concerned discharges as per the code of practice [22a, b-23].

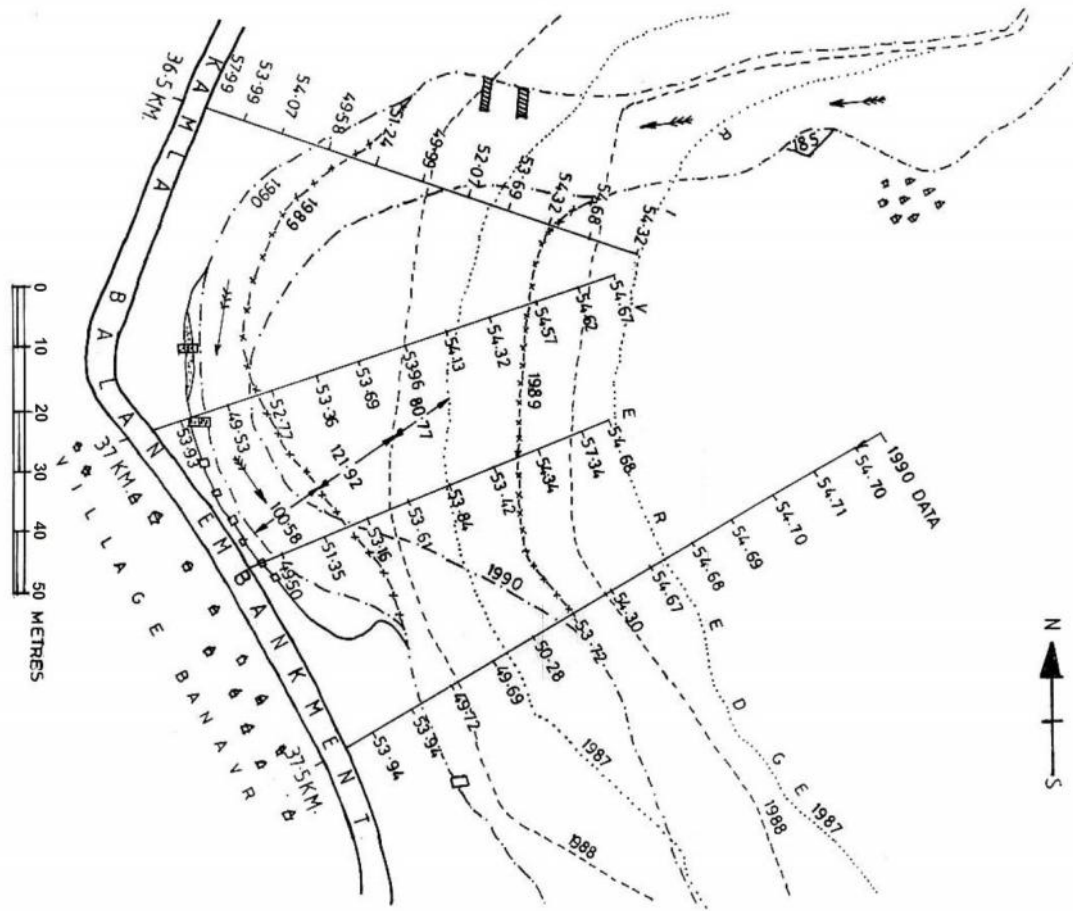


Figure 3. Plan and sectional elevations (reduced levels in m) at km 37 of the river Kamla-Balan right bank embankment.

4. Results and Discussion

4.1 Status of Anti-erosion Works

At 37 km section (Figure 3) [21]: During 1987 construction of five Sal-bullah spurs normal to the bank at different key points and a pilot channel was executed before the flood, but Sal-bullah spurs were not found enough to prevent bank erosion. All spurs except one collapsed due to first flood in the same year. Further, there was a proposal to protect 330 m length of embankment by boulder revetment on suitable filter media as

well as to divert the shifted course by a new pilot channel. This stretch near village Banuar failed many years including breach in 2002.

Section at 62 km (Figure 4): In order to stop bank erosion and shifting of the river at 62 km, a tie band used to be in practice frequently during 1975-80 on the right

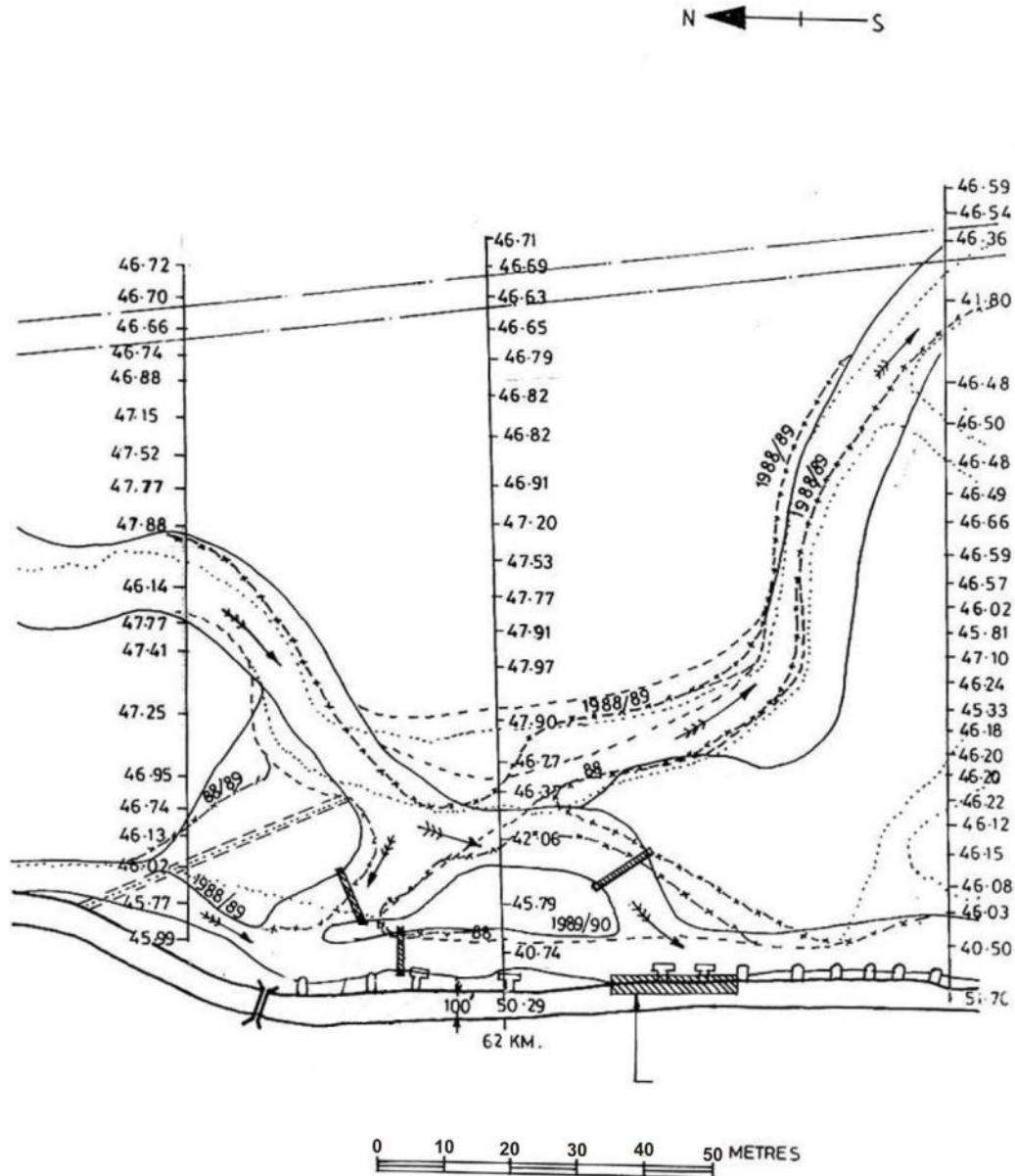


Figure 4. Plan and sectional elevations (RL in m) at km 62 of the river Kamla-Balan right bank embankment.

bank along the river edge. The tie band washed away in 1987 flood; river changed its courses and started flowing parallel and adjacent to the main right embankment,

resulting in breaches at three different locations. Both, boulders and sand bags tied together by nylon nets and placed in position between Sal-bullah piles to protect the toe of the embankment portion. After 1987, screen of Sal-bullah and brick bed bars constructed several times, but the active erosion at downstream or upstream continued. Further, boulder revetment proposed and boulder revetment constructed on tie band using flexible jute mat as a filter media and a seasonal measure, and found functional to some extent but with less durability.

4.2 Hydrological and Hydraulic Properties

Flood-flow stage and discharge information have been determined for the study sections, 37 km and 62 km, based on the Central Water Commission observation at 50.5 km near Jhanjharpur. The deepest bed level of the river at 50.5 km is 44.15 m asl (RL), whereas it is 49 m (RL) at 37 km and 40.5 m (RL) at 62 km. The danger level, mean flow level and Highest Flood Level at 50.5 km are 50 m, 50.85 m and 52.73 m (RL), respectively. Interesting and surprising to note that danger level is above the mean flow level, means the sections are liable to face flood hazard during normal flow as well. Catchment area up to Jhanjharpur site is 2945 sq km ^[15]. At this section, the monsoon mean flow in the river is 1119 cumecs. Average annual rainfall in the area is 140 cm. Estimated flood peak based upon analysis of annual flood peaks data series using different frequency distributions^[24] at 10, 50, and 100 years of return periods are 1656, 2188 and 2413 cumecs, respectively ^[16]. The PH value of floodwater measured on 22 September 1991 is 6.92, means water is slightly acidic. Sieve analysis result (Figure 5) of soil samples representing riverbed, riverbank and its base through particle size distribution curves the mean particle size (d_{50}) for riverbed and bank base found as 0.018 mm and that of the riverbank soil particle mean size was only 0.05mm. These fine particles are very much erodible with velocity above 0.3 m/s.

Figure 6 (a & b) show river cross-sections at 37 km and 62 km, respectively. Average height of the embankment is 8 m and distance between east and west embankment is about 2 km. Table 1 shows the flood discharge and other hydraulic features computed based upon Slope–Area method using Manning’s’ equation (the governing equations, parameters and variables are defined in the concerned columns). The perimeter and cross-sectional area of the river at 62 km with water elevation of 49.8 m are 819 m and 2820 m², respectively. An average slope of the riverbed is 0.317 m/km.

Table 1. Abstract of hydrological parameters computed and estimated for the River Kamala Balan at both the sections, km 37 and km 62 at up-stream and down-stream of Jhanjharpur at 50.5 km.

Location	HFL	Area (A)	Hydraulic Radius ®	Rugosity Coeff.(n)	Conveyance Factor (K)	Bed Slope (S)	Avg.(Q) Flood Discharge	Velocity V = Q/A	Normal Scour (m)
km	m	m²	(A/P)m	N	(1/n) AR ^{2/3}	Average	Q=(1/n)* AR ^{2/3} *S^0.5 Cumecs	m/s	Silt factor (f=0.3)
36.8	56.98	1847.6	3.3	0.045	91499	0.00036	1781	0.93	0.3
37.0	56.90	1557.6	3.3	0.045	77404	or 1 in			
37.3	56.81	2318.4	3.4	0.045	117232	2784			5.4
61.7	49.92	2248.2	2.9	0.045	102458	0.00032	2327	0.88	0.3
62.0	49.80	2820.1	3.4	0.045	142904	or 1 in			
62.5	49.63	2910.1	3.6	0.045	152287	3151			6.4
Normal Scour Depth =1.34(((Q/400)**2)/f)^0.333; At 37 km = 5.4 m & Section 62 km = 6.4 m									

The estimated flow velocity at 49.8 m (RL) of flow depth is 0.88 m/sec. The estimated flow velocity at 56.9 m (RL) of flow depth at Section 37 km is 0.93 m/sec. The normal scour depth calculated at section of km 37 and km 62 is 5.4 m and 6.4 m, respectively (Table 1). The radius of meandering and its curvature at 37 km is 500 m. It has-been developed due to shifting of the river courses towards the embankment by 300 m in 1987, 100 m in 1988 and 200 m in 1989. As a result of progressive shifting, it was flowing only 30 m away in 1990 and 20 m away in 1991 to the embankment whereas, at the section of 62 km the river is braided and main flow runs parallel to the embankment striking and touching up to 3 km downstream.

4.3 Control Measures and Materials

The spurs, groynes and revetment works are anti-erosion measures to check bank erosion and to protect the embankment ^[25-26]. Groynes may be impermeable or permeable type. Permeable type may be of tree spurs, timber stakes or wooden piles, stoned filled in balli crates, or stone filled in wire crates (Gabions). It may be placed as per site requirement to function as reflecting, attracting or normal type (Figure 7). According to National Policy, an anti-erosion work should normally be taken-up only for protection of towns, residential areas, railway line, roads, group of thickly populated villages and agricultural lands, where the benefit-cost ratio justifies such works. National Water Resources

Council (NWRC) adopted National Water Policy on flood protection measures and co-operation, a centrally sponsored scheme, namely Critical Anti-erosion works in Ganga Basin States. The study sections are important on the above points of view.

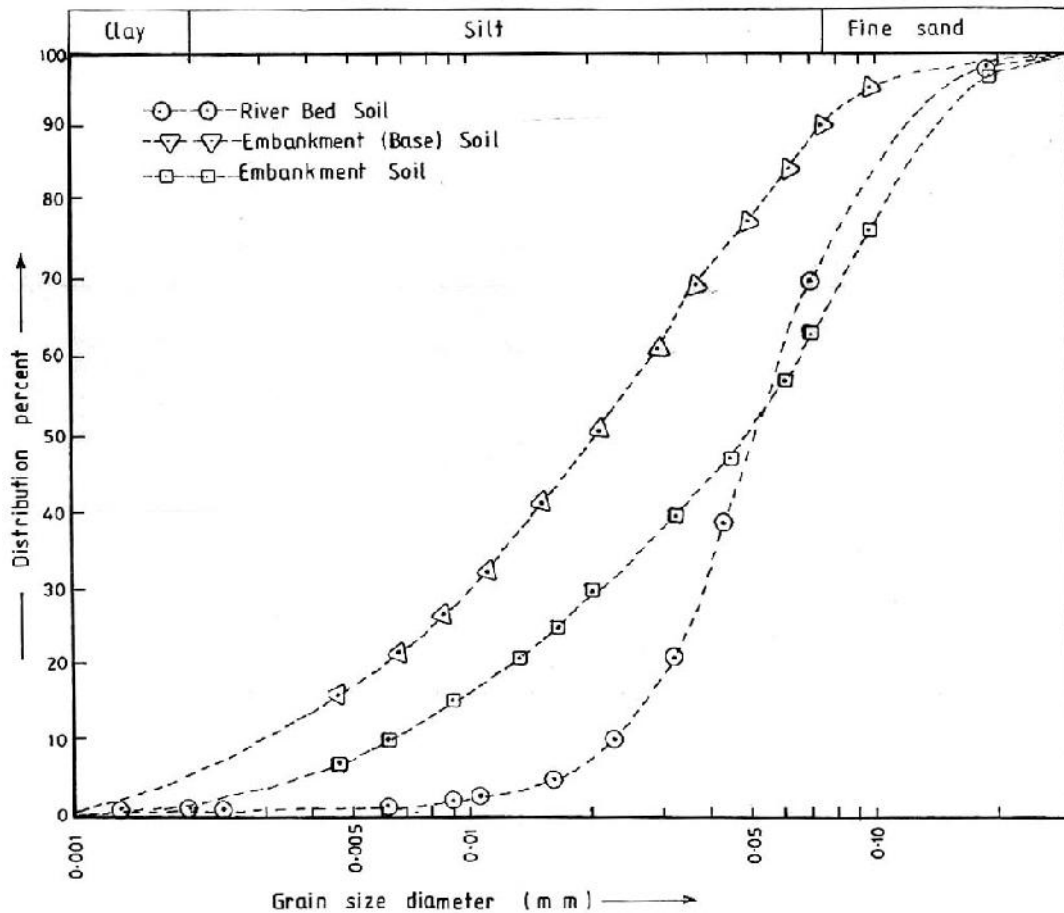
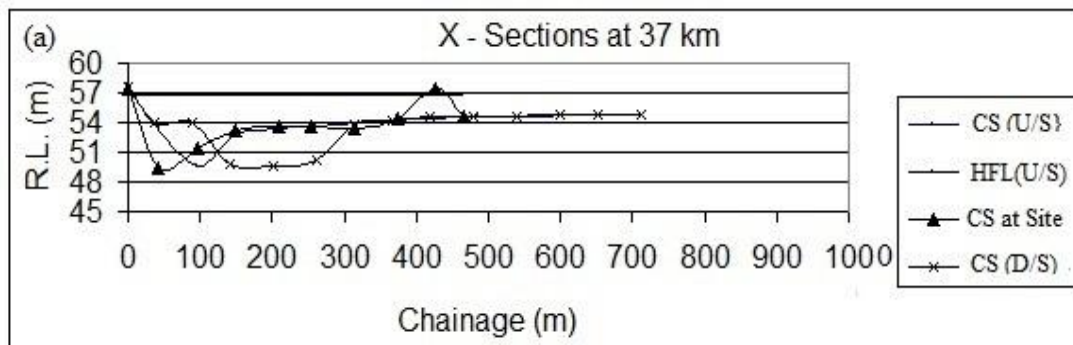


Figure 5. Grain size distribution curves based on sieve analysis of soil samples representing riverbed, embankment slope and base material of the embankment.



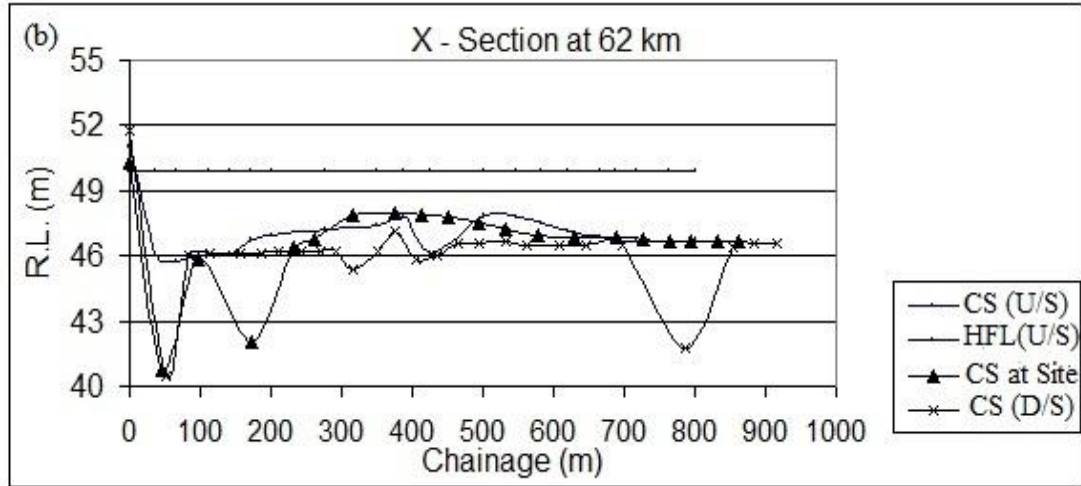


Figure 6. Cross-sections at (a) 37 km, 210m u/s and 260m d/s from km37, and (b) 62 km, 375m u/s and 525m d/s from km 62.

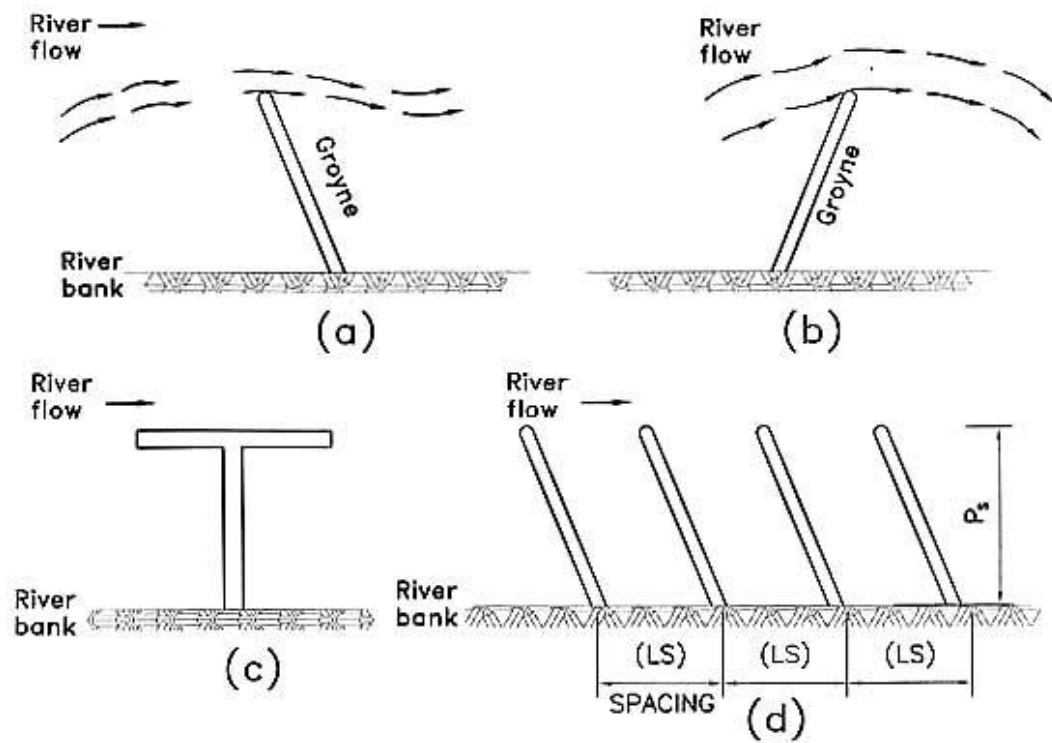


Figure 7. Typical hydraulic structures to divert the flow and protect the river bank/embankment, ie. Groyne layout options (a) repelling type, (b) attracting type, (c) normal type or (d) system for repelling type.

Engineering properties ^[26a-b] (porosity, tensile and puncturing strength) of an opted typical polypropylene Geo-textile (having fabric strips of white colour, woven one

up and one down, 0.56 mm thick, 200 gm/m² of surface area, 22 number of threads per cm in wrap direction and 32 numbers in weft direction with maximum pore sizes of 230 micron) conducting laboratory tests ^[26a]. The average tensile strength under wrap and weft directions was 4640 kg/m and 3380 kg/m, respectively.

Based on the characteristics of both the study sections, the geo-textile aided revetment design as per grain size distribution of each layer (Figure 8) shows that a layer (A), of 10 cm thick coarse sand above natural soil, then a geo-textile layer (B) covered by 15 cm thick gravel layer (C), and a water front material (stone boulder) layer of at least 20 cm thick satisfy stability, filter and uniformity criteria ^[26a]. Geo-textile reinforced revetment section (Figure 9) found suitable for the soil particle size and flood flow velocity analysed as 0.93 and 0.88 m/sec for the study sections at 37 and 62 km, respectively. However, as per site condition thickness of pitching layer may go up to 0.75 m for slope and 1.4 m for launching apron.

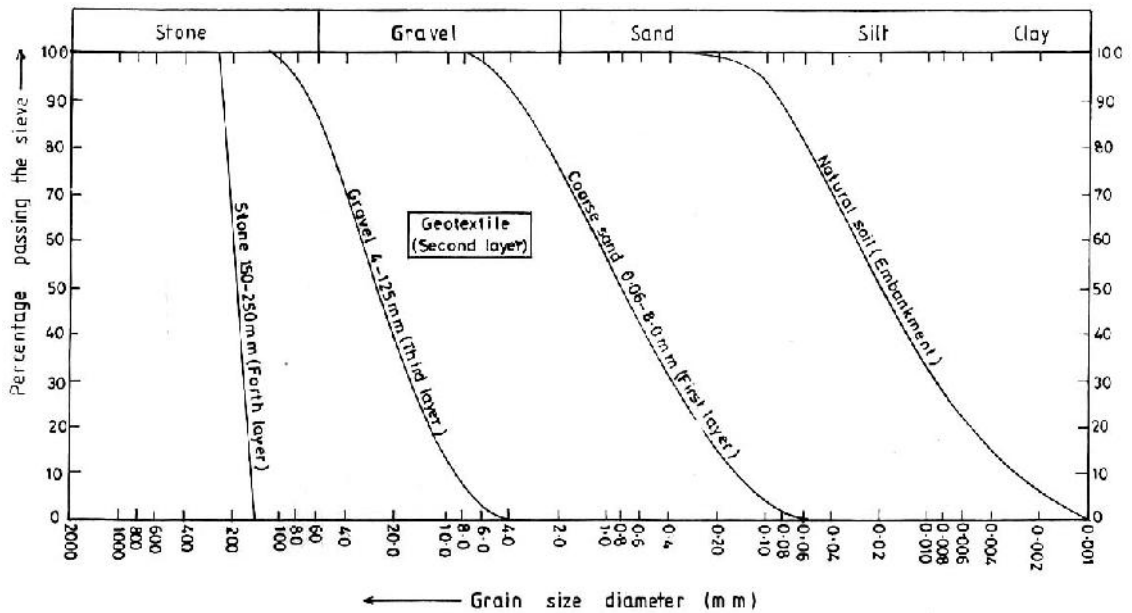


Figure 8. Shows silt, gravel and boulders size distribution curve, proposed for minimum thickness of riprap slope revetment.

4.4 Model Test

A model test was performed to know the effectiveness of the geo-textile under conditions similar to that of the field ^[26a]. A physical model, similitude to the site characteristics and side slope of 2:1 was constructed using disturbed local soil. As per

design, the tested geo-textile sheet was laid over the slopes from toe to a height above estimated water level. The geo-textile sheet was anchored and a riprap of 60 mm stone material was laid over it. Flood depth and velocity (maximum up to 1.2 m/sec) of varying magnitudes were created to test the performance.

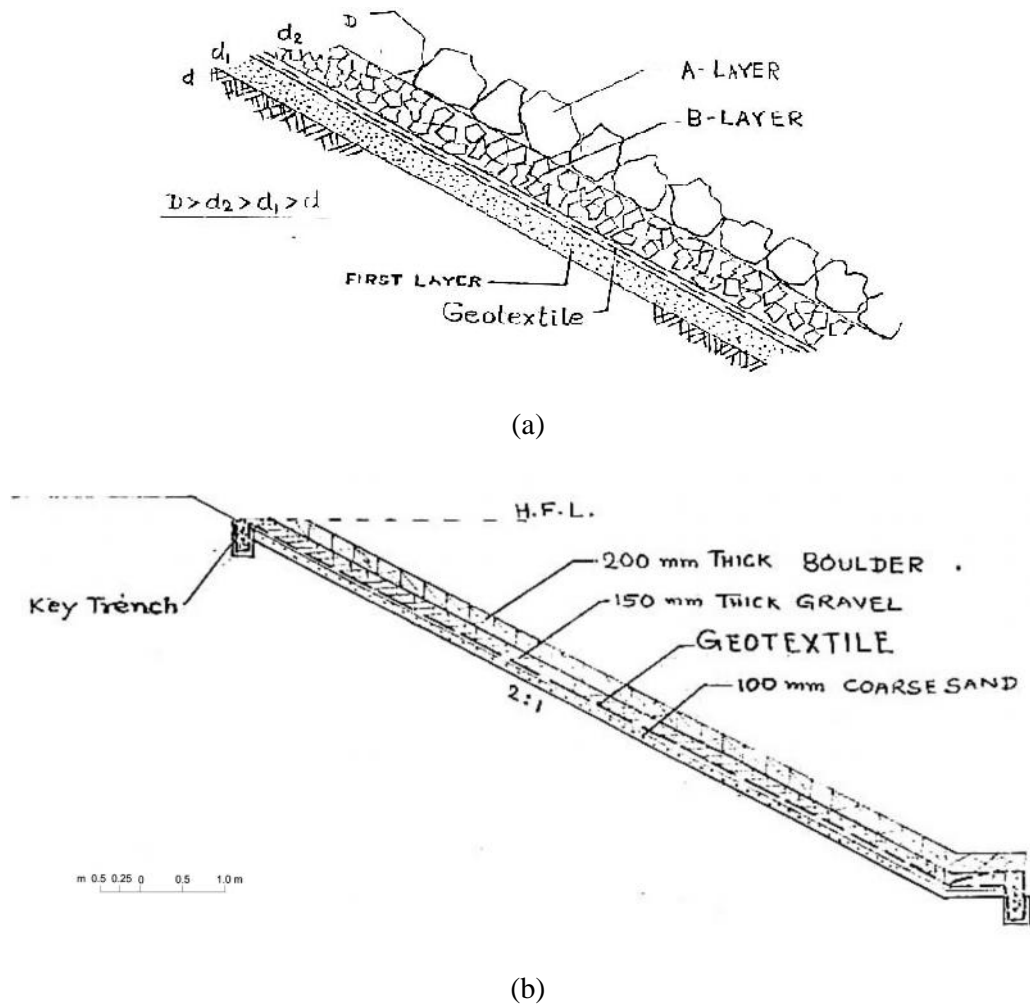


Figure 9. Shows the sectional elevation of (a) typical sand based filter and (b) proposed geo-synthetic based filter for bank protection revetment.

Further, a similar test conducted without using geo-textile layer. It has been found that the test performed using geo-textile was safe and there was not any sign of displacement of pitching material or dislocation of foundation material underneath. Whereas, foundation/base material eroded without a layer of geo-textile at a flow velocity above 0.3 m/sec.

5. Conclusion

Forecasting the situation supported by Remote Sensing data, Geographic Information System and field visits are essential to monitor the changes in the river topology and to take corrective and protection measures. Flood fighting measures like patrolling and mobility on embankment just by fighting squad are not sufficient to combat risk of failure of embankment by river erosion.

Lack of required input on anti-erosion works and adequate protection of embankments restrict risk free situation. This may be due to failure of conventional approaches and foundation materials. The foundation materials are silty-soil with d_{50} of 0.018 mm for the river bed and 0.05 mm for bank slope, which may get eroded and transported at the flow velocity above 0.15 m / sec. While velocity analysed at the study sections 37 and 62 km was 0.93 and 0.88 m/sec, respectively

Study shows that an application of woven type Polypropylene geo-textile with sufficient pores to dissipate pore pressure can restore the foundation material. Woven Geo-textile commonly called 'silt fence' and used as barriers in the embankment construction to hold fine soil particles from migration due to river flow velocity as well as wave action. Above the geo-textile sheet riprap pitching of 15 cm thick gravel of 30 mm to 125 mm sizes and more than 20 cm thick water front stone boulders above 200 mm size may be suited to protect the embankment at the study section. The geo-textile reinforced revetment may act as a rescue against the alarming situation of cutting and erosion in the river Kamla Balan. The protection has to be done up to scour depth also as per provision of relevant codes available and others. The normal scour depth calculated at section of km 37 and km 62 is 5.4m and 6.4 m, respectively.

However, due to lack of durability against wire meshing and environmental consideration the cost-benefit analysis is required to be studied further taking an account of direct, indirect and opportunity cost-benefit in the long run. This may not be final solution to protect entire stretch of the embankment but problem prone areas of embankment are very much needed to be studied in this light for safety and sustainability with certainty.

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