



SLOPE PROTECTION WORKS FOR A HIGHWAY EMBANKMENT IN FLOODPLAINS- A CASE STUDY OF GANGAPATH EXPRESSWAY

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Engineering a Better Solution





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Introduction

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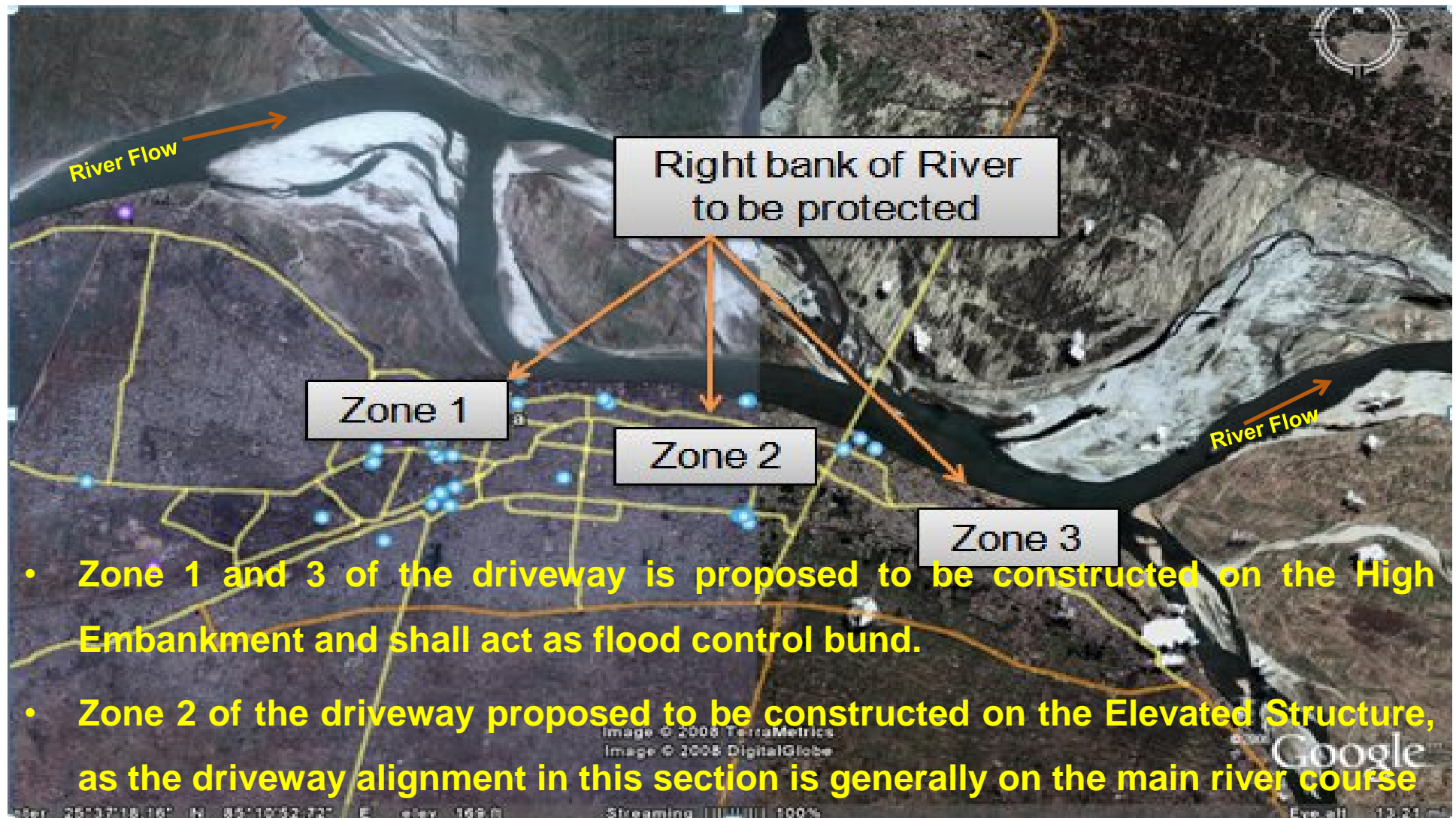
- Floods are recurrent phenomena in India from time immemorial.
- Bihar is India's most flood-prone state, with 73.06% flood affected area.
- Erosion of the river banks during floods or peak rainfall periods have become recurring disaster.
- which on an annual basis destroys thousands of human lives apart from livestock and assets worth millions causing enormous problem for the people and the Government in the state of Bihar, India.
- Presentation walks through a case study for a highway embankment '**Gangapath Expressway**' along the Ganga River where erosion control and flood protection measures were adopted

Project details

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- Construction of Ganga Path is a 21.5 km long Expressway from Digha to Didarganj at Patna in the state of Bihar.
- The road embankment portion of this expressway runs along the left bank of river Ganga which is regularly affected by fury of floods.
- The entire Ganga Path has been categorized into three zones:
 - ✓ Zone 1: Digha to Gandhi Maidan (km 0.00 to km 5.900): 5.9kms
 - ✓ Zone 2: Gandhi Maidan to Dulli Ghat(Km 5.900 to km13.500) 7.6kms
 - ✓ Zone 3: Dulli Ghat to Didarganj - (km 13.500 to km 21.500)-8.0kms





Right bank of River to be protected

Zone 1

Zone 2

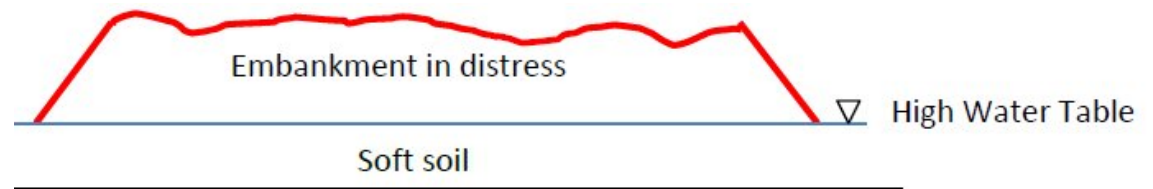
Zone 3

- Zone 1 and 3 of the driveway is proposed to be constructed on the High Embankment and shall act as flood control bund.
- Zone 2 of the driveway proposed to be constructed on the Elevated Structure, as the driveway alignment in this section is generally on the main river course

Major Challenges

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- Patna : High Seismic Prone – Zone IV
- High Embankments- 7m to 14m
- High Liquefaction Potential
- Very poor Soil properties Excessive settlements > 600mm
- Silty sand/ Clay with very low bearing capacity i.e. soft soil varying from 2 to 10m deep
- High Flood level condition- Structure adjacent and closely running along the longest River “Ganga”
- Limited availability of stones necessitates their minimum use for protection works and further optimizing cost



Initial Site Photographs

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Proposed alignment of road embankment along the river



Presence of soft soil in the existing strata of the road embankment

Ground Improvement Works

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- The construction of the Gangapath involved extensive ground improvement.
 - Removal and Replacement (0.5m to 2m)
 - Basal reinforcement with high strength geogrid (strengths 100kN/m to 1200kN/m)
 - Dynamic compaction.



Embankment Protection Works

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Annexure of Preliminary Project Report (Hydraulic & Hydrologic Report, April 2013)

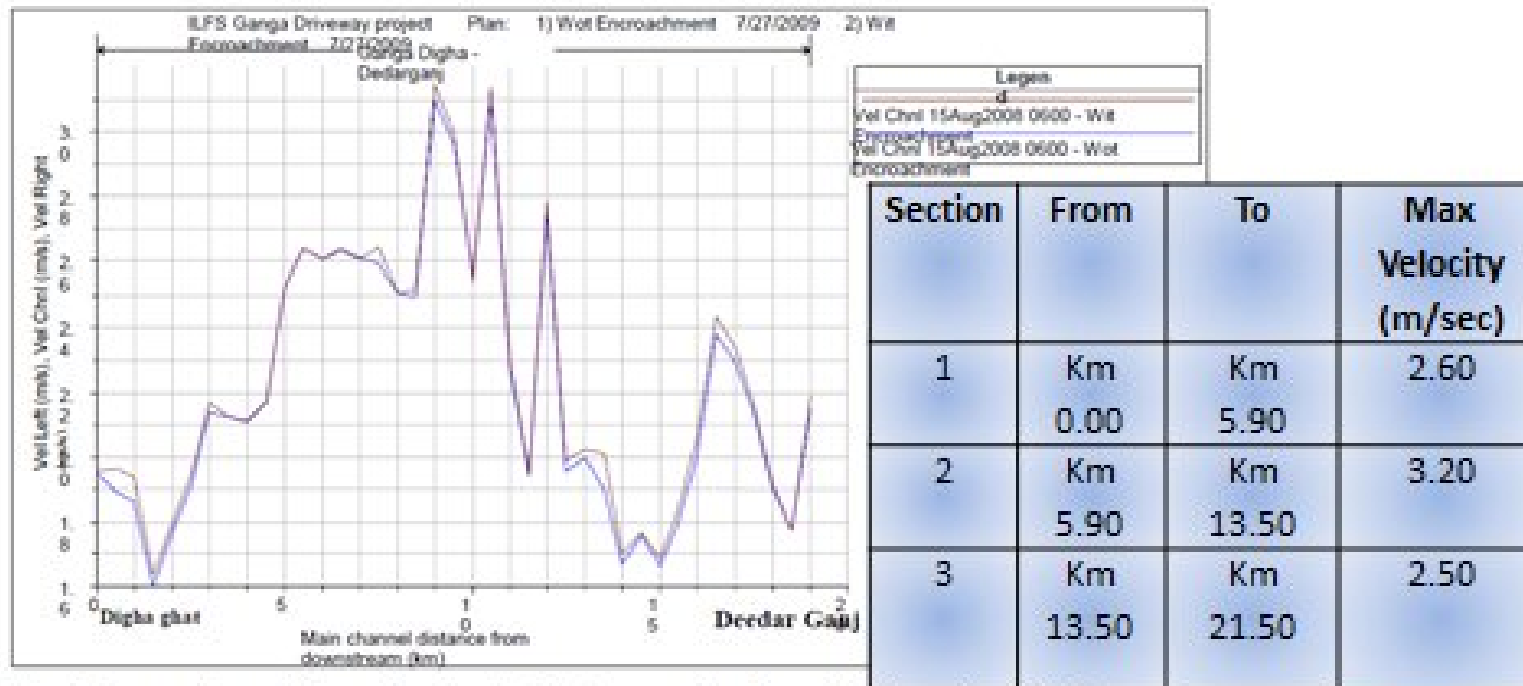
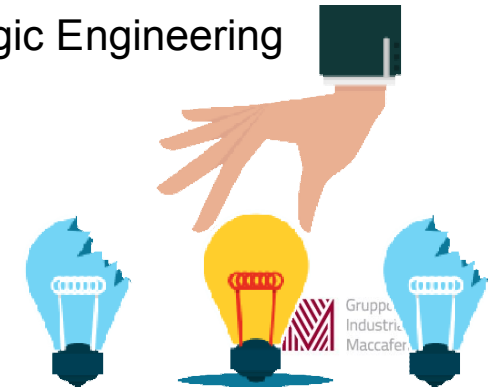


Fig. 8 Comparison of flow velocities in the river reach with and without the embankment and longitudinal bridge

Selection Of Embankment Cross-section

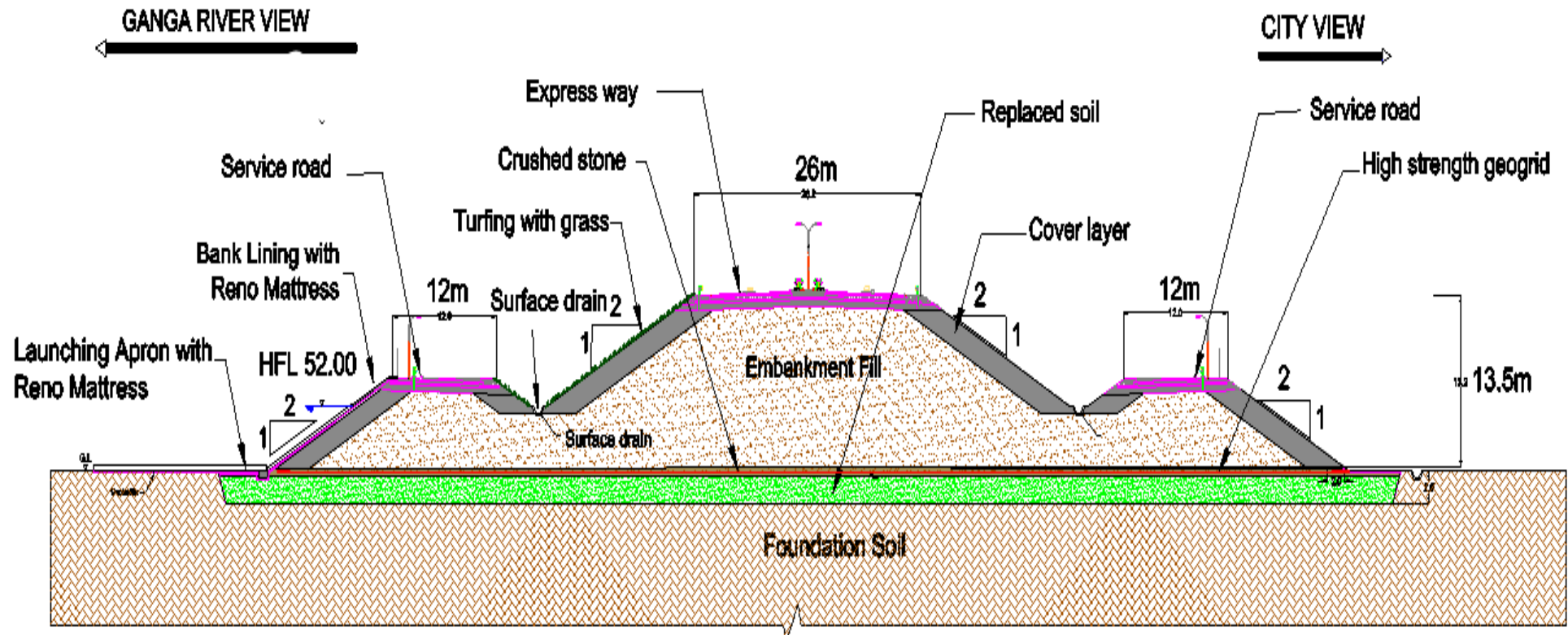
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- Mostly embankment is exposed to no hydraulic head and during flood events, the embankment has to withstand a rapid rise in water level on the riverside.-
Embankment Protection Critical Parameter
- Model studies & analysis was carried by Maccaferri and IIT Roorkee for selecting the most suited cross section.
- The hydraulic/hydrological impacts of placement of embankment along the right bank of Ganga have been studied through mathematical model Hydrologic Engineering Center's River Analysis System (HEC-RAS).



Geometry of embankment

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Selection Of Embankment Protection Works

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- Stability of unprotected highway banks have to be assessed carefully in the process of selection and design of suitable protection measures.
- The ideal protection work consists:
 - Cover layer to resist hydraulic impacts of flow like tractive shear force and velocities.
 - Filter layer in between cover layer and core materials is responsible to prevent migration of subsoil particles (retention criteria) and at the same time to allow movement of water through the designed filter (permeability criteria).



Embankment Protection Works- Cover/ Armor layer

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- Stone Pitching is the most sorted protection system for the embankment slopes
- One major drawback to the use of Pitching is that they are more sensitive to local economic factors.
- Patna being a mining banned city, the availability of large quantities of stones is an issue.
- Also, the freight/haul costs of stones satisfying the design requirement from different far-off place significantly affect the cost of the revetments.
- Considering the above aspects, Reno mattresses were selected for protection works

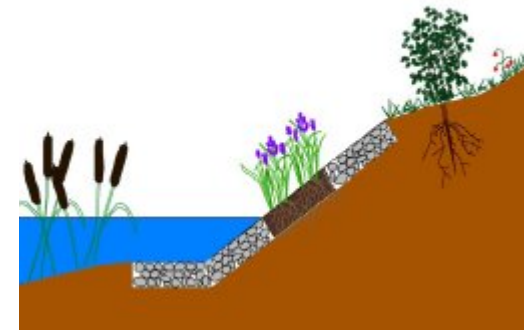
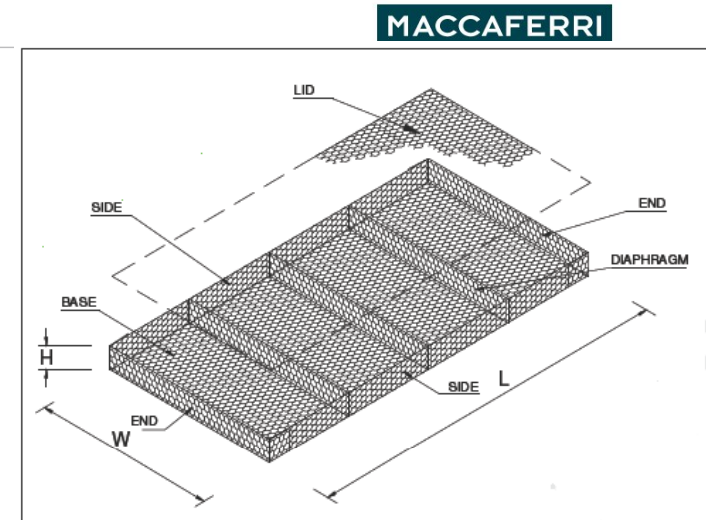


Reno Mattress

Rectangular cages in variable sizes of double twisted hexagonal mild steel wire mesh with zinc and PVC coating (MoRTH 2500, 2013)

Merits of Revet mattress:

- Thickness may be reduced to less than 50% thickness of a loose riprap
- Cost of protection works with Reno mattresses is approx. 30% less than the Stone pitching/Riprap
- Being monolithic structure, capability of withstanding dynamic stresses induced by flow.
- Quicker and easier installation
- Gabions/Reno mattress being a monolithic homogeneous flexible structure, it tolerates differential settlement without failure.



Embankment Protection Works- Filter layer

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- Filter prevents **excessive migration** of base soil particles, permits **relief of hydrostatic pressure** beneath and **distributes the weight of revetment** to provide more uniform settlement.
- The traditional filter material is gravel or crushed rock or coarse sand.
- Geotextiles can be a better alternative considering lesser cost, easy to install, better quality control, less carbon footprint etc.
- Non-woven geotextiles are preferred over woven geotextiles. Non-woven geotextiles have more **friction to resist sliding as well as high puncture resistance** as compared to woven geotextiles. .
- Non-woven fabrics can **stretch more** and can **conform to irregular surfaces** better than woven geotextiles.



Design for Filtration

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Mechanisms of Filtration- Two conflicting requirements

❖ *Prevention of excessive migration of soil particles*

The filter **must retain soil**, implying that the size of filter pore spaces or openings should be smaller than a specified maximum value.

❖ *While at the same time allowing liquid to flow freely*

The filter **must be permeable enough** to allow a relatively free flow through it, implying that the size of filter pore spaces and number of openings should be larger than a specified minimum value.



Design for Filtration

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Geotextile filter requirements:

- **Retention**: Ensures that the geotextile openings are small enough to prevent excessive migration of soil particles.
- **Permeability**: Ensures that the geotextile is permeable enough to allow liquids to pass through without causing significant upstream pressure buildup.
- **Anti-clogging**: Ensures that the geotextile has adequate openings, preventing trapped soil from clogging openings and affecting permeability.
- **Survivability**: Ensures that the geotextile is strong enough to resist damage during installation.
- **Durability**: Ensures that the geotextile is resilient to adverse chemical, biological and ultraviolet (UV) light exposure for the design life of the project.

Design for Filtration

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Retention Criteria:

$$\text{AOS or } O_{95(\text{geotextile})} \leq B D_{85(\text{soil})}$$

$C_u \leq 2$ or ≥ 8 :

$$B = 1$$

$2 \leq C_u \leq 4$:

$$B = 0.5 C_u$$

$4 < C_u < 8$

$$B = 8/C_u$$

For Sands, gravelly sands, silty sands and clayey sand; B is a function of uniformity coefficient

for *wovens*,

$$B = 1; O_{95} \leq D_{85}$$

for *nonwovens*,

$$B = 1.8; O_{95} \leq 1.8 D_{85}$$

and for *both*,

$$\text{AOS or } O_{95} \leq 0.3 \text{ mm}$$

For Silty and clays, B is a function of geotextile type

Design for Filtration

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Permeability/Permittivity Criteria:

For less critical applications and less severe conditions:

$$k_{\text{geotextile}} \geq k_{\text{soil}}$$

For critical applications and severe conditions:

$$k_{\text{geotextile}} \geq 10 k_{\text{soil}}$$

$\psi \geq 0.5 \text{ sec}^{-1}$ for < 15% passing 0.075 mm

$\psi \geq 0.2 \text{ sec}^{-1}$ for 15 to 50% passing 0.075 mm

$\psi \geq 0.1 \text{ sec}^{-1}$ for > 50% passing 0.075 mm

Design for Filtration

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Clogging Criteria:

For $C_u > 3$

$$O_{95} \text{ (geotextile)} \geq 3 D_{15} \text{ (soil)}$$

For $C_u < 3$

Select a geotextile with maximum AOS value from Retention criteria

Design for Filtration

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Survivability Criteria:

Table: 700-1: Minimum Geotextile Strength Property Requirements

Installation condition	Type	Strength Property Requirement (MARV)							
		Grab Strength in Newton (N) as per ASTM D 4632 / IS 13162 Part 5		Tear Strength in Newton (N) as per ASTM D 4533 / IS 14293		Puncture Strength in Newton(N) as per IS 13162 Part 4		Burst Strength in Newton (N) as per ASTM D 3786 / IS 1966	
		Elongation at Failure							
		<50%	>50%	<50%	>50%	<50%	>50%	<50%	>50%
Harsh installation condition	Type 1	1400	900	500	350	500	350	3500	1700
Moderate Installation condition	Type II	1100	700	400	250	400	250	2700	1300
Less Severe Installation condition	TypeIII	800	500	300	180	300	180	2100	950

Table: 700-2: Requirements for Ultra Violet Stability

S.No	Properties of Fabric	Requirements(Retained Strength)
1	Grab Strength	Not less than 70% after 500 hours of exposure
2	Tear Strength	
3	Puncture Strength	
4	Burst Strength	

Design of Bank protection works

CIRIA C683

Popular Manual CIRIA C683 mentions the relationship of Gabion mattress thickness w.r.t flow velocities.

3.14.3.2 Hydraulic properties of gabions

The response of gabions and gabion mattresses to current attack has been the subject of a large number of commercial and research projects. Recent research has led to critical and limiting velocities which take account effects of turbulence. The critical velocity is defined in literature as the velocity required to initiate movement of the stones within the gabion mattress and the limiting velocity is the velocity at which the gabion mattress reaches the acceptable limit of deformation. For gabion mattresses under current attack it was found that mattresses with a thickness of 150 mm have a limiting velocity of 2–3.5 m/s, while mattresses with a thickness of 300 mm can resist velocities of 4–5.5 m/s. Box gabions can be suitable for the protection of river beds and banks subject to heavy current attack and can be stable at flow velocities of the order of 5–6 m/s (or more, depending on the quality of construction and assembly).

Gabion Mattress / Reno Mattress (Thickness)	Limiting Velocity
150 mm	2 – 3.5 m/s
300 mm	4 – 5.5 m/s
500 mm	5 - 6 m/s

Design of Bank protection works

FHWA-IP-89-016; Hydraulic Engineering Circular No. 11- Design of Riprap Revetment

Table 5. Criteria for gabion thickness.

Has provided

'Criteria for Gabion Thickness'

w.r.t

Bank Soil Type

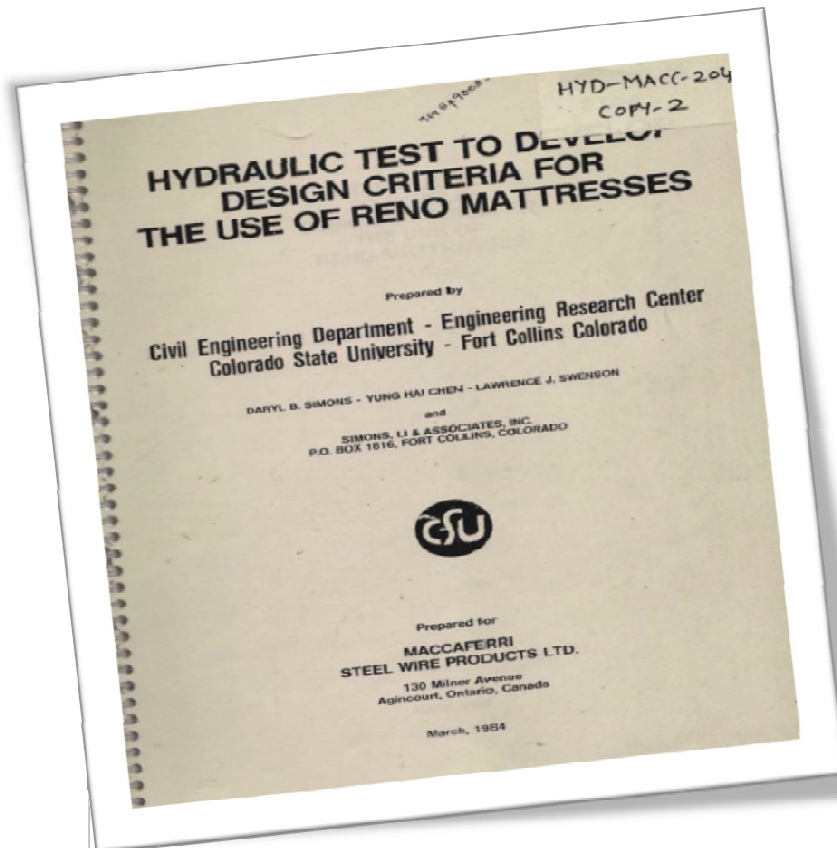
Maximum Velocity

Bank Slope

Bank Soil Type	Maximum Velocity (ft./sec.)	m/sec	Bank Slope	Min. Required Mattress Thickness (inches)
				mm
Clays, heavy cohesive soils	10	3.0	< 1:3	9
	13 - 16	3.9 - 4.9	< 1:2	12
	any		> 1:2	≥ 18
Silts, fine sands	10	3.0	< 1:2	12
Shingle with gravel	4			304
	16	4.9	< 1:3	9
	20	6.1	< 1:2	12
	any		> 1:2	≥ 18

Design of Bank protection works

Extract from report of model studies conducted in Colorado university



Mattress
Thickness
(inches) **mm**

6 **152**
9 **228**
12 **304**
457

Critical Velocity Determined
From This Study
(fps) **m/sec**

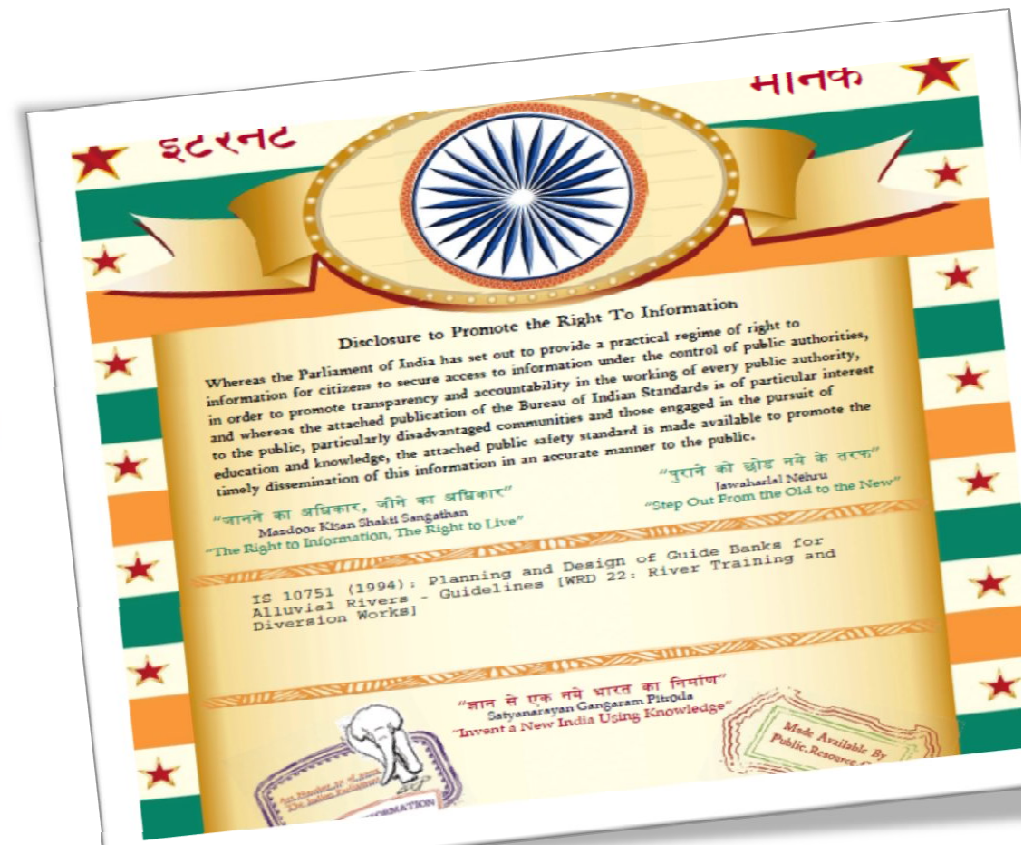
	<u>F < 1.5</u>	<u>F > 3</u>
✓	14.5 4.42	12.1 3.68
	15.4 4.69	13.0 13.0
	16.4 5.00	13.8 4.20
	18.3 5.57	15.6 4.75

Design of Bank protection works

IS 10751 : Planning and Design of Guide Banks for Alluvial Rivers - Guidelines [WRD 22: River Training and Diversion Works]

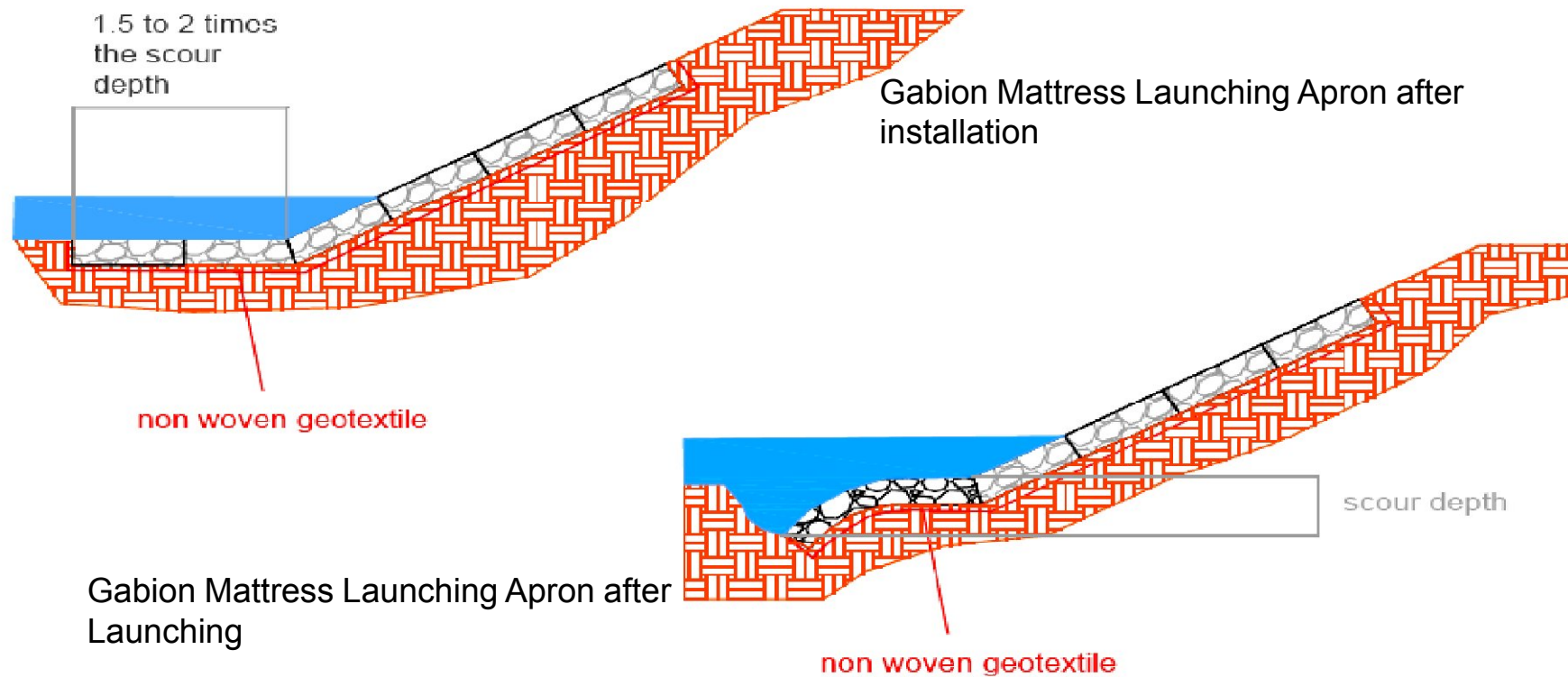
$$T = \frac{V^2}{2g(S_s - 1)}$$

$D = 0.473 (Q/f)^{1/3}$ for waterway equal to or more than Lacey's waterway.



Design of Bank protection works

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Design of Bank protection works

Thickness Of Launched Apron

From IS 10751 clause 5.6.2 thickness of launched apron should be 25% to 50% greater than the thickness of pitching on the slope

Scour depth

$$D = 0.473 (Q/f)^{1/3}$$

Length of launched Apron = 1.5 X Design Scour Depth.

As Per CWC guidelines, if the length of launched apron is reduced than the required, thickness should be increased proportionately

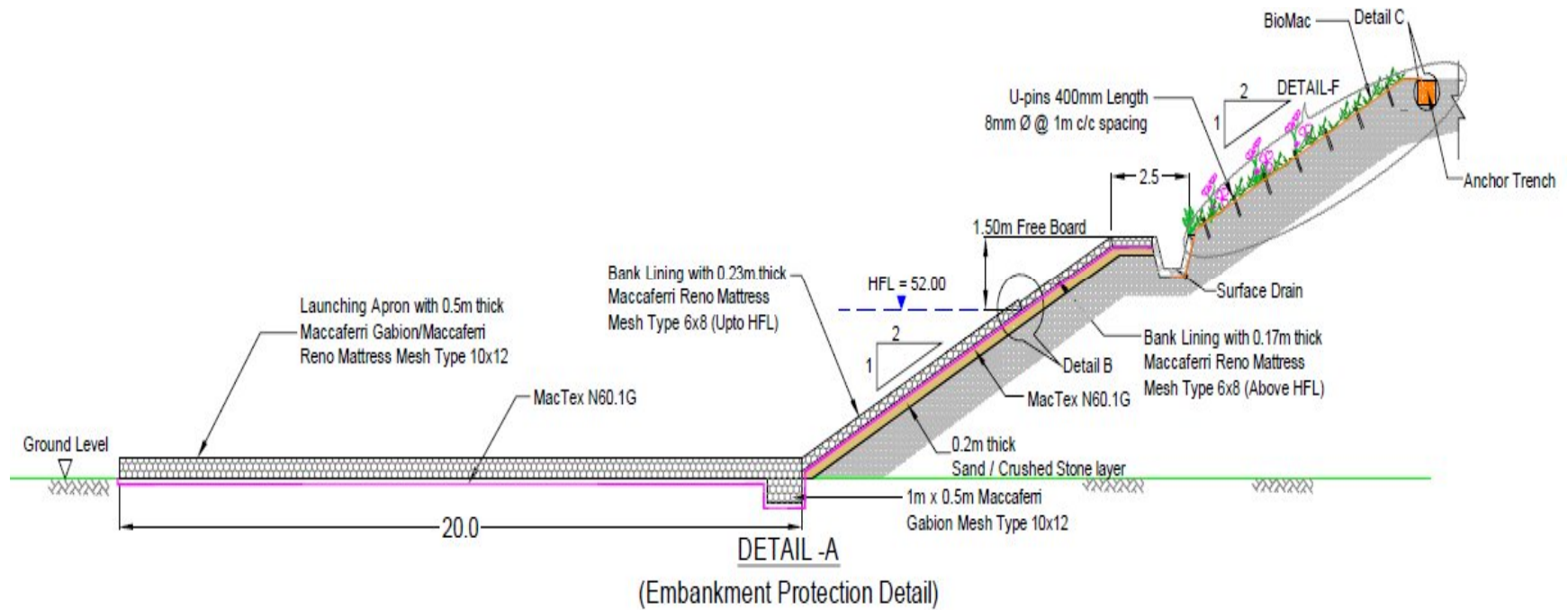
Design of Bank protection works

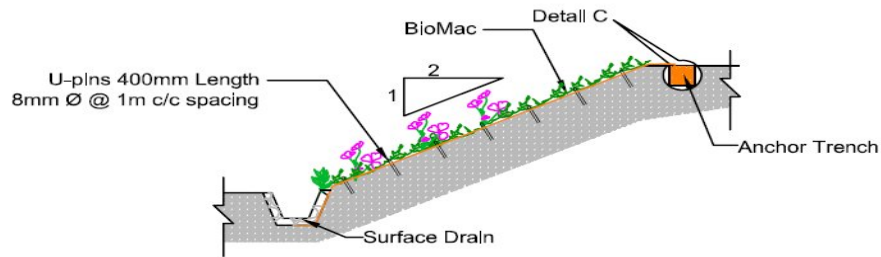
Embankment Protection Works

Following are the different thickness of mattresses adopted based on the design

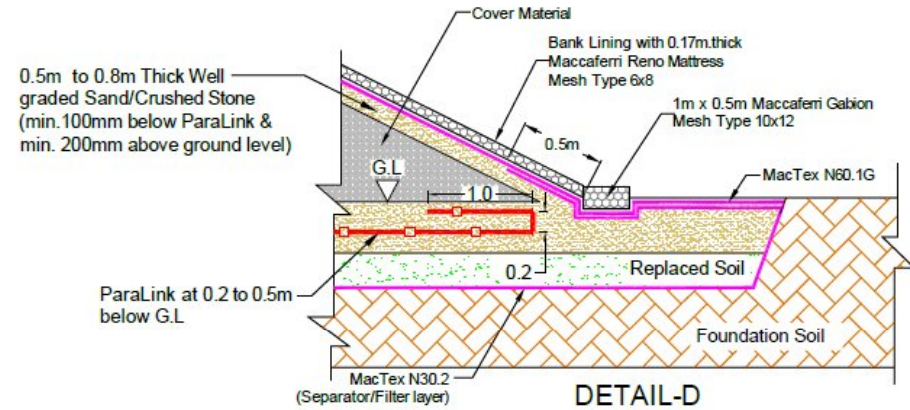
- 0.23 m thick Reno mattresses is provided between Low Water Level (LWL) and High Flood Level (HFL).
- 0.17m thick Reno mattresses is provided between the HFL and berm. Because, the probability of flood more than HFL is low .
- Slope above the berm level is protected with biodegradable coir mat for promotion of vegetation to control the erosion.

Embankment Protection Works



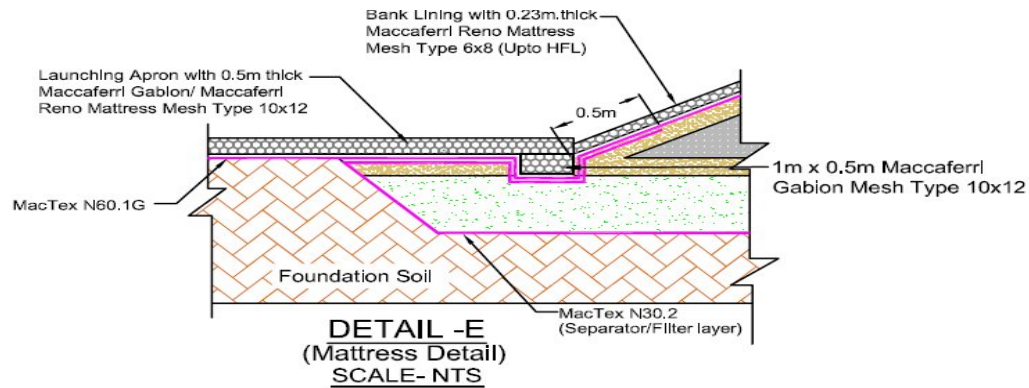


DETAIL -F
(Embankment Protection Detail)
SCALE- NTS



City Side

River Side



Construction - Laying of geotextile

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Protection measures – Under construction

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Conclusion

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- **Mathematical model HEC-RAS** was used to estimate the flood level in the river for discharge of 150 years return period. Accordingly the geometry of the embankment was fixed with berm level 1.5m above design HFL with a side slope of 1:2.
- Based on the slope and design calculations, protection works were provided with **Revet mattresses/gabion mattresses** for the prevention of slope erosion and scouring at the toe of embankment.
- Conventional sand/gravel filters were replaced by non woven geotextile.
- **Embankment protection works** adopted with flexible systems made the maximum optimization of stones hence reduced the overall cost.

Thank
you

