INCOLD

CENTRAL BOARD OF IRRIGATION & POWER
ESTD. 1927
NEW DELHI

CLIMATE-RESILIENT DAMS AND

HYDROPOWER INFRASTRUCTURE

INTEGRATING

ENVIRONMENTAL SUSTAINABILITY

IN PLANNING AND DEVELOPMENT

Sustainable Infrastructure Design and Operations

Minimol Korulla, Maccaferri Environmental Solutions Pvt Ltd, India

List of Contents

- Challenges faced by Climate Resilient Dams & Infrastructure
- Sustainable Infrastructure – A System Perspective
- Role of Riverbank Protection in Dam & Hydropower Projects
- Principles of Sustainable Infrastructure design
- Sustainable Riverbank Protection Strategies
- Sustainable/Flexible solutions
- Design Aspects
- Case Histories
- Codal Provisions
- Conclusions

Climate Resilient Dams & Infrastructure

Challenges:

- Increasing frequency of extreme floods and rapid drawdown events
- Altered river flow regimes due to climate variability
- Accelerated soil erosion and slope instability
- Growing stress on dams, hydropower assets, and associated infrastructure

Sustainable Infrastructure

A System Perspective:

- Dams and hydropower projects function within river systems
- Sustainability depends on:
  - Upstream catchment stability
  - Reservoir rim and bank protection
  - Downstream channel stability
- Riverbank protection is a supporting pillar of dam resilience

Sustainable Infrastructure

Role of Riverbank Protection in Dam & Hydropower Projects:

- Controls sediment inflow into reservoirs
- Protects reservoir periphery and appurtenant structures
- Mitigates downstream erosion due to regulated releases
- Enhances safety of access roads, powerhouses, and spillway channels

Sustainable Infrastructure

Principles of Sustainable Infrastructure design:

- Design for climate uncertainty, not historical averages
- Preference for flexible and adaptive systems
- Minimize environmental footprint
- Lifecycle-based design approach
- Balance structural safety with ecological considerations

Sustainable Infrastructure

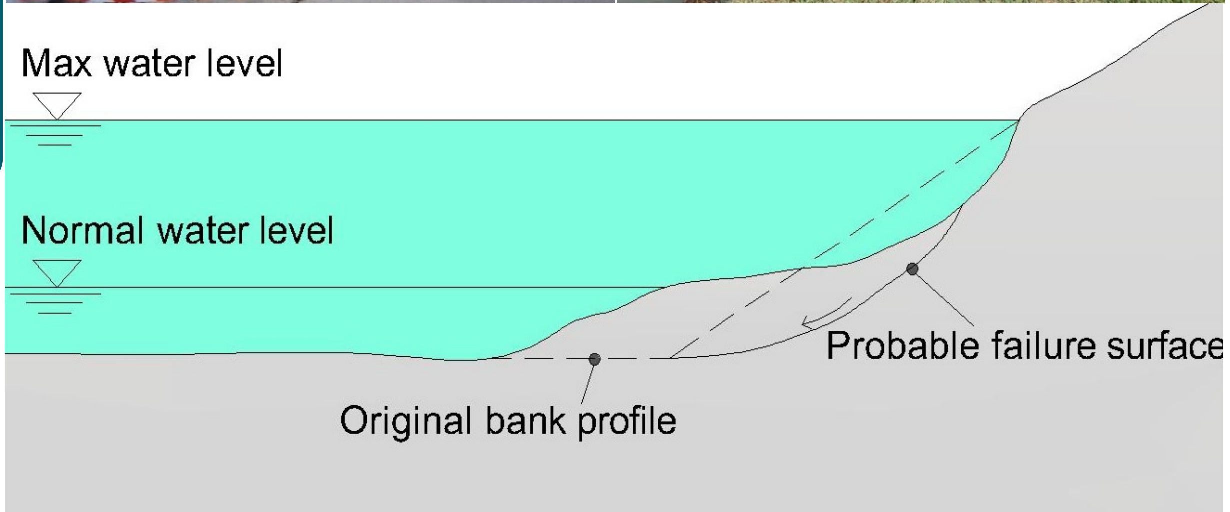
Sustainable Riverbank Protection Strategies:

- Bio-engineering and nature-based solutions
- Reinforced soil and geosynthetic-based systems
- Reduced dependence on rigid concrete linings
- Use of locally available materials
- Hybrid solutions (soft + hard measures)

Bends – Erosion at toe causes embankment stability

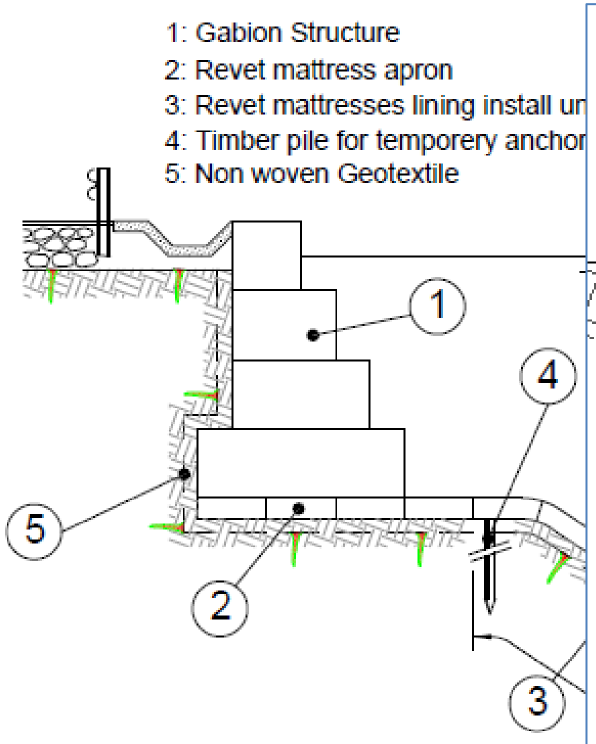
ALONG THE RIVER BANK

PROBLEM

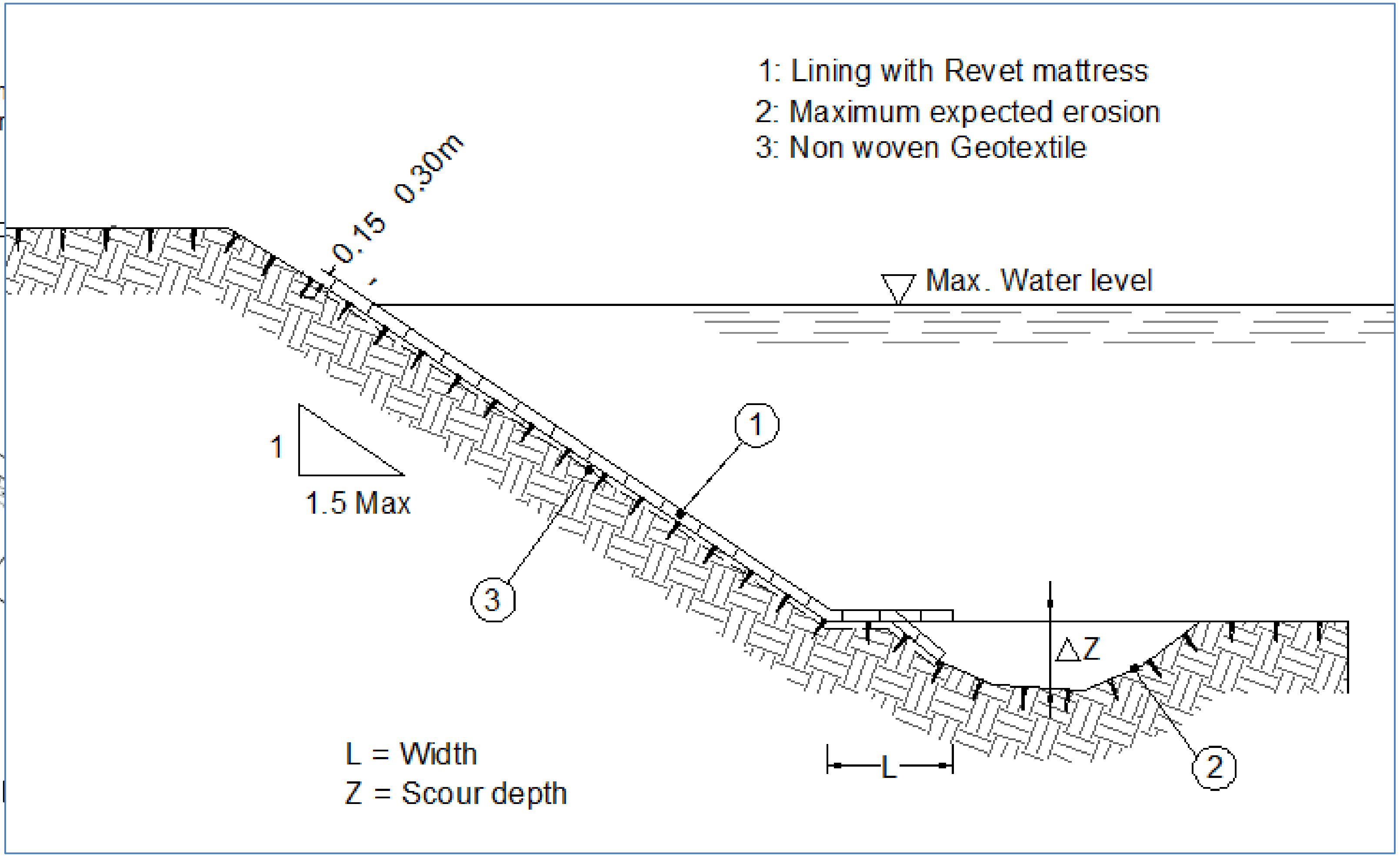


SOLUTION

Typical Sketches of Riverbank Protection

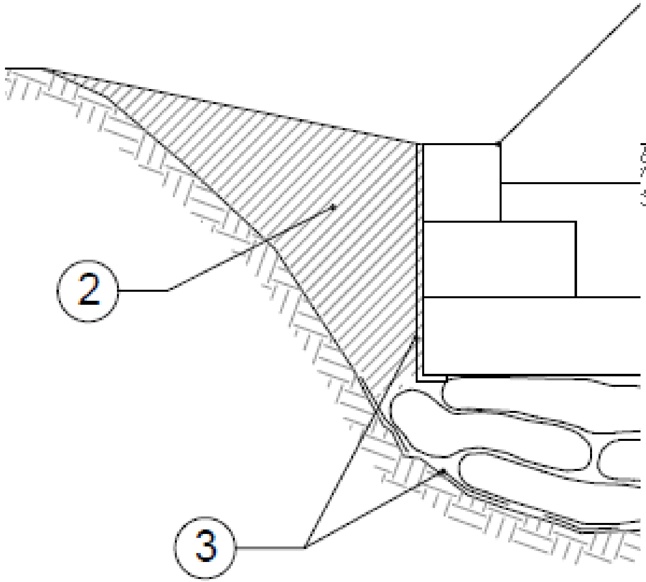


Typical section of gabion retai

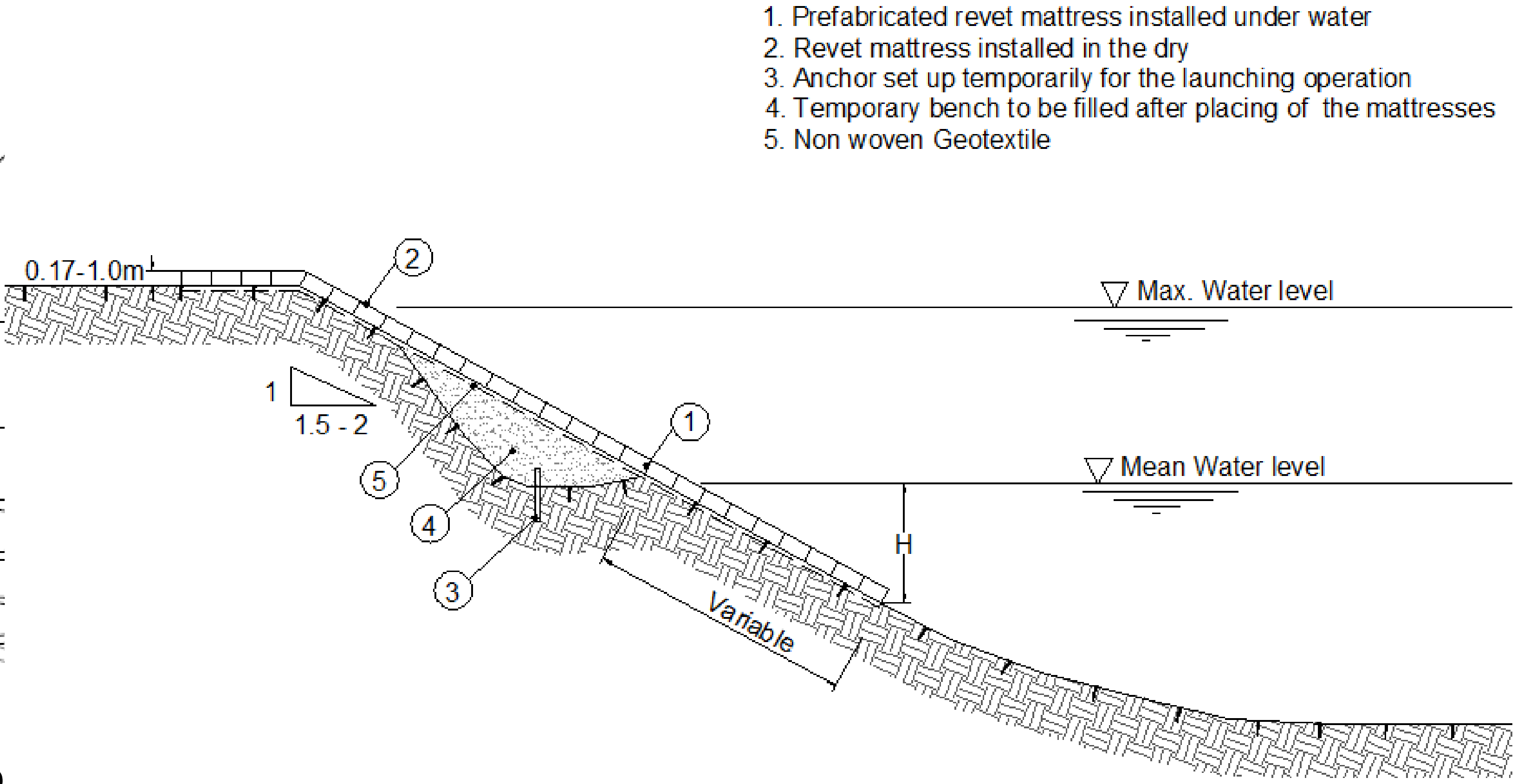


Typical section of gabion mattress for lining

Typical Sketches of Riverbank Protection

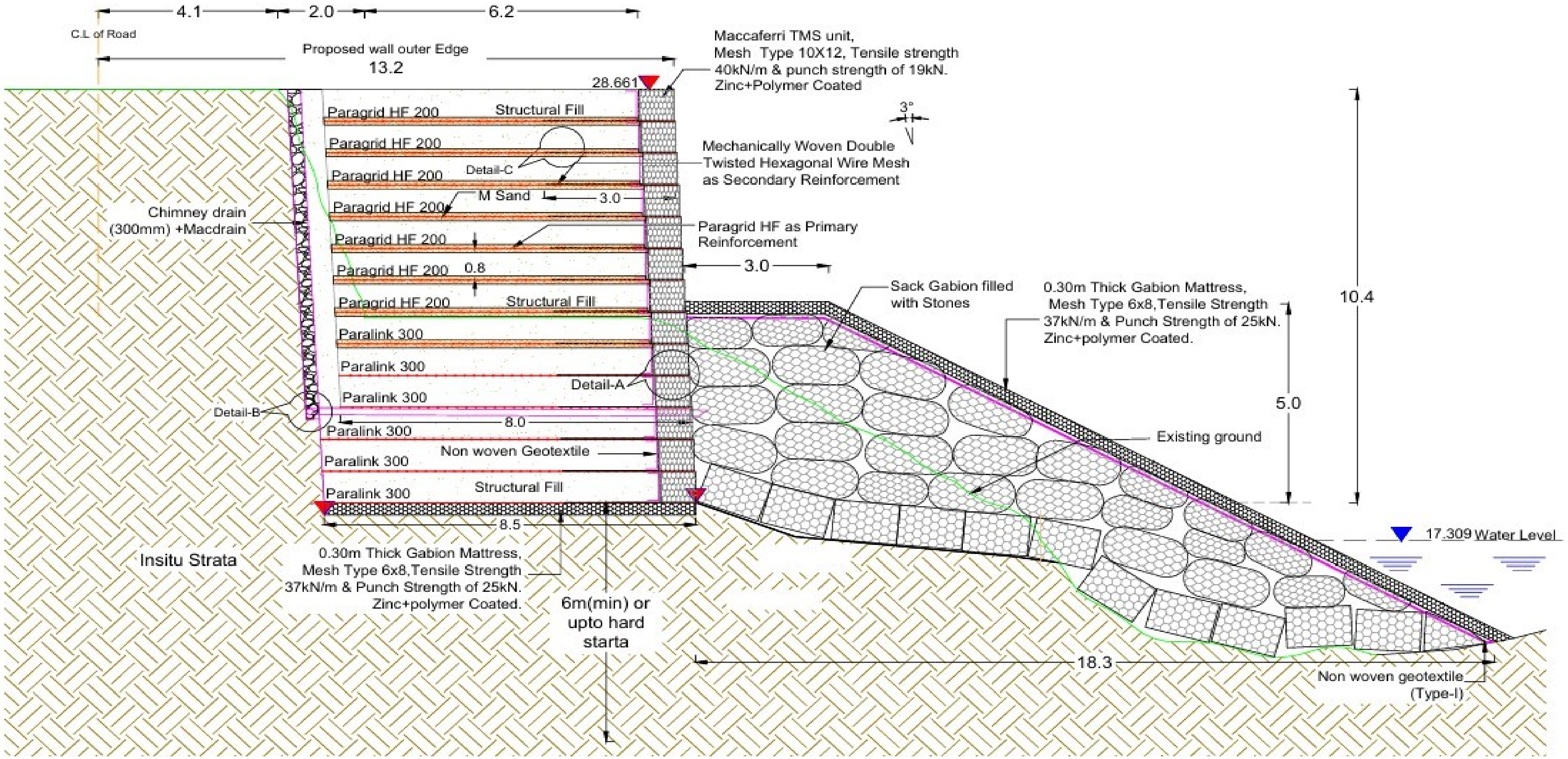


Structure built o



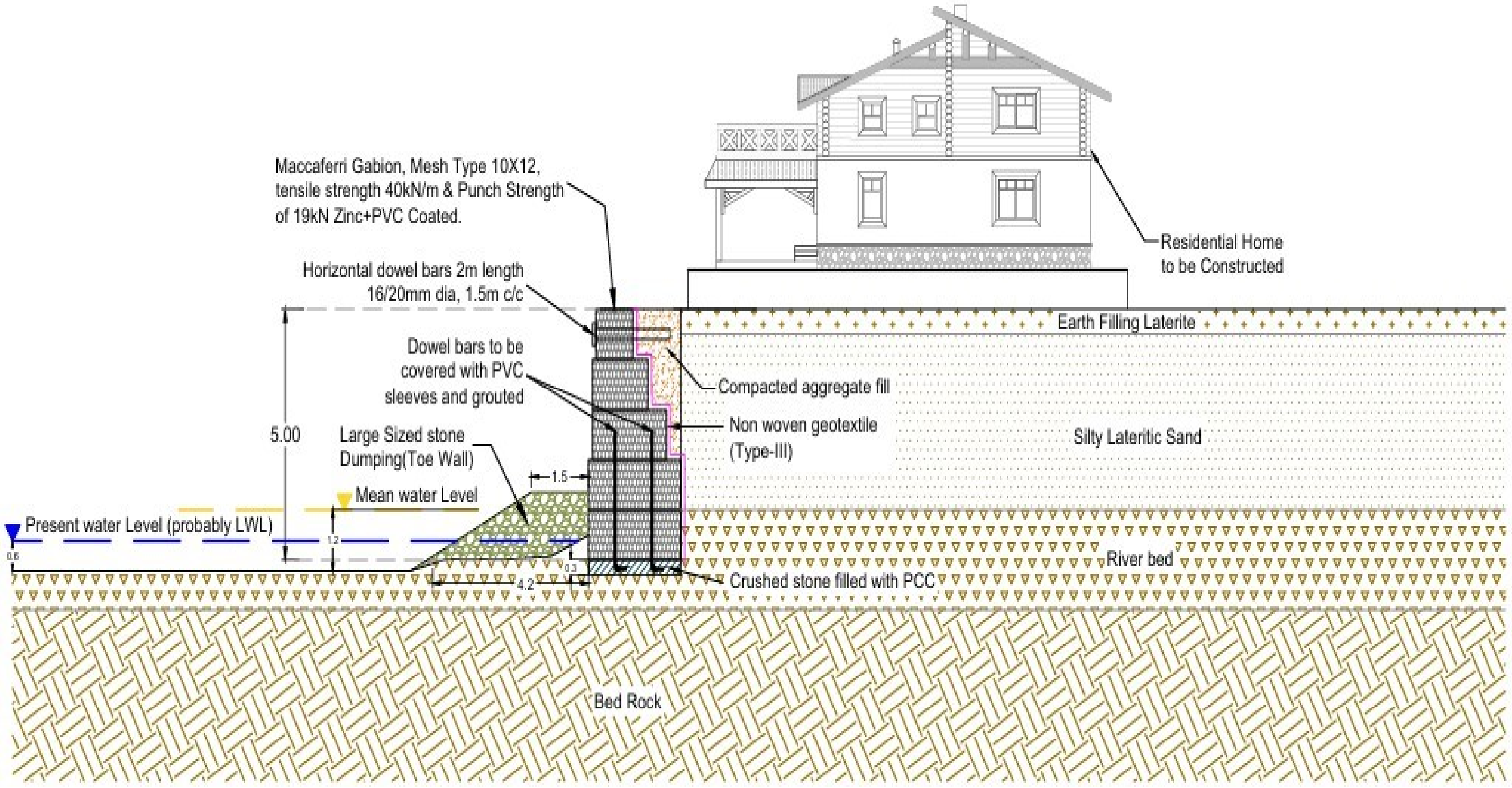
Bank lining with revet mattress installed under the water

Typical Sketches of Riverbank Protection



River Slope Retention using Reinforced Soil Structure & toe protection counter berm with cylindrical gabions, gabion mattress

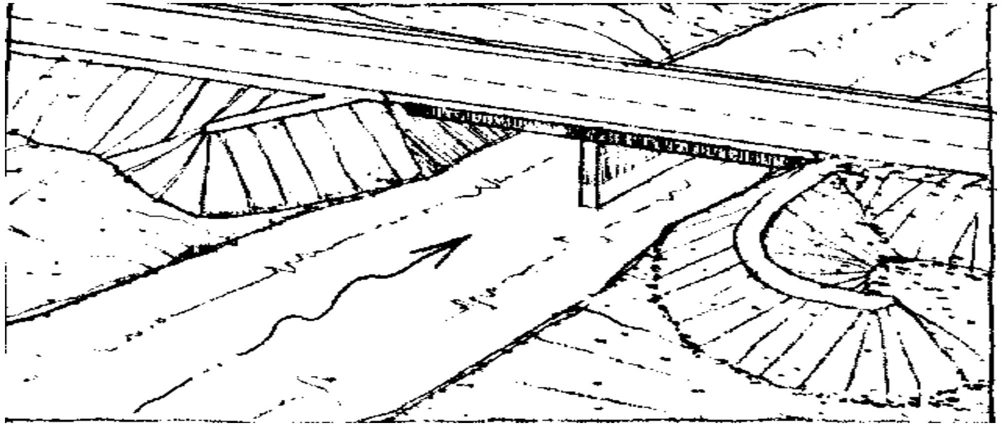
Typical Sketches of Riverbank Protection



River Slope Retention using Gabion walls & toe protection with large size boulders

Bends – Erosion at Bridge Abutments

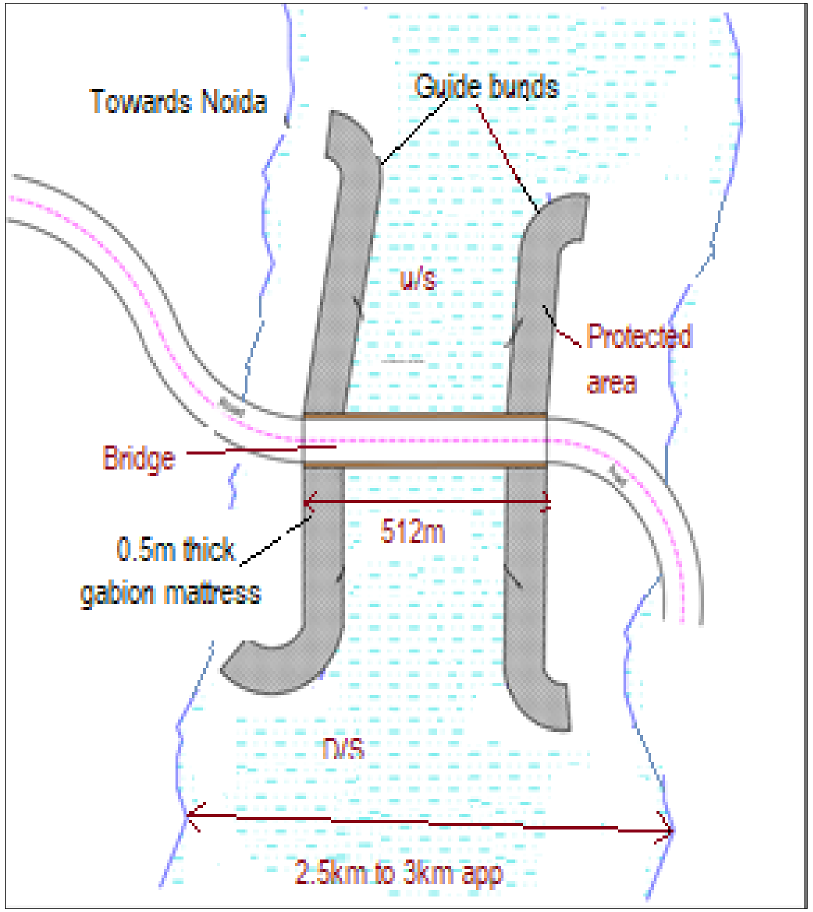
ALONG THE RIVER BANK



PROBLEM

SOLUTION

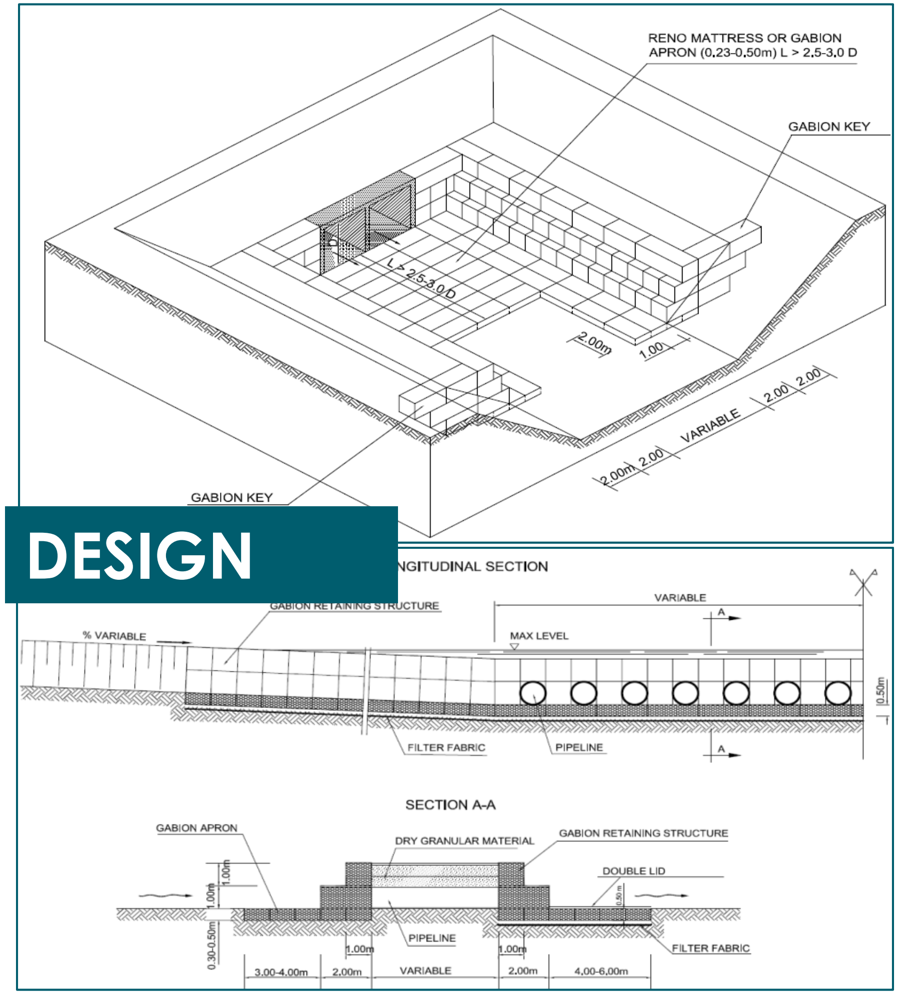
Bends – Erosion at Bridge Abutments



Plan drawing showing gabion mattress as scour/erosion protection

Culverts Headwalls & River Crossing

ACROSS THE RIVER SECTION



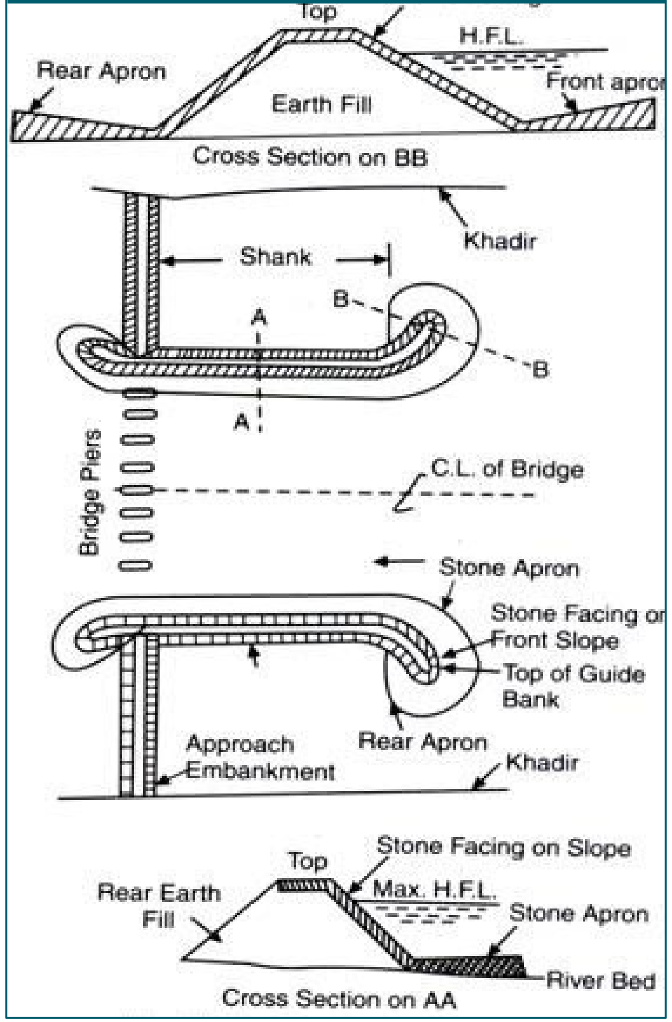
DESIGN

SOLUTION

Guide bunds

ACROSS THE RIVER SECTION

DESIGN



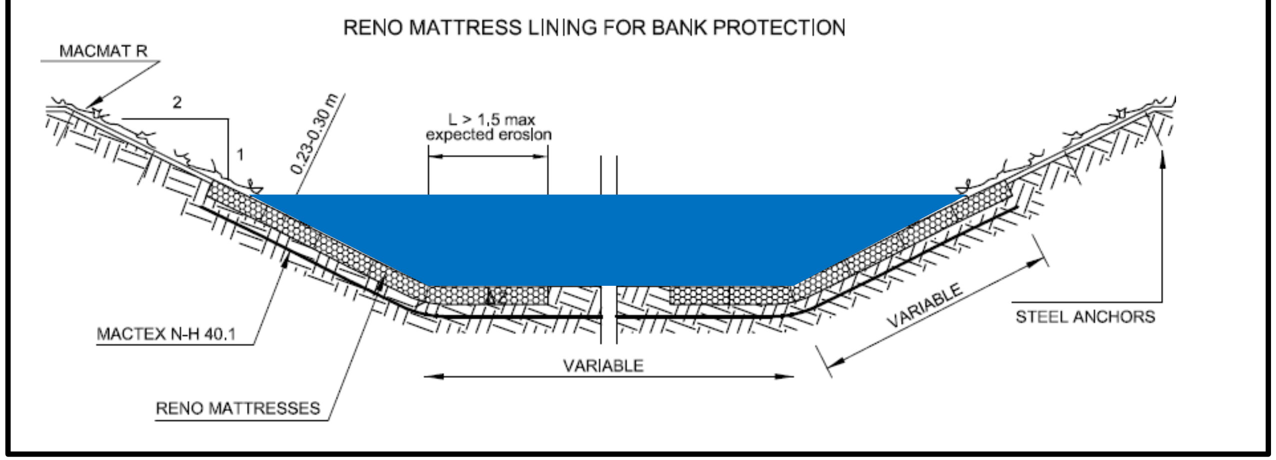
SOLUTION

Channelized Streams

DRAINAGE

SOLUTION

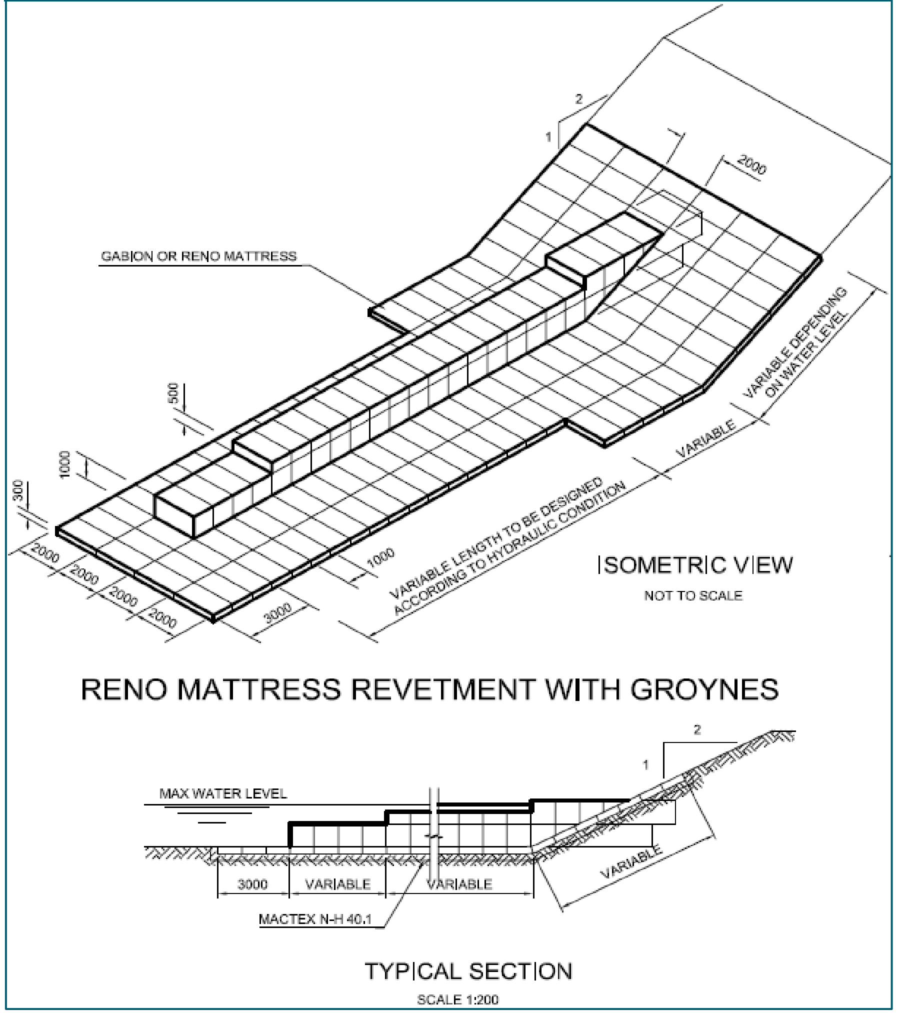
DESIGN



Groynes

MEGANDERING CONTROL

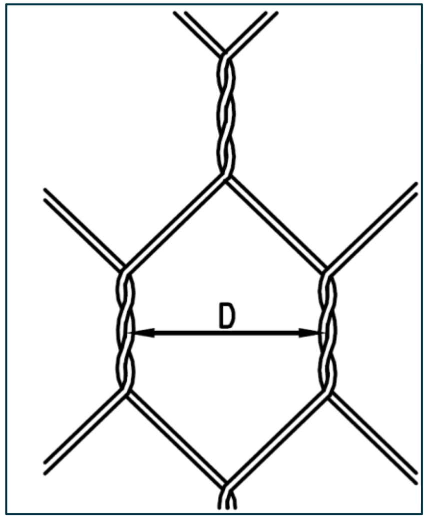
DESIGN



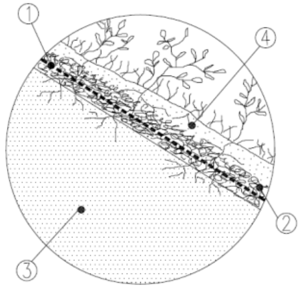
SOLUTION

Flexible Solutions & Advantages

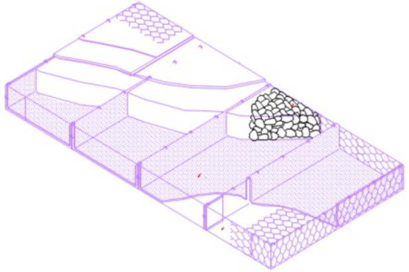
MESH TYPE	MESH WIRE DIA (mm)
6 X 8	2.2
10 X 12	2.7, 3.0



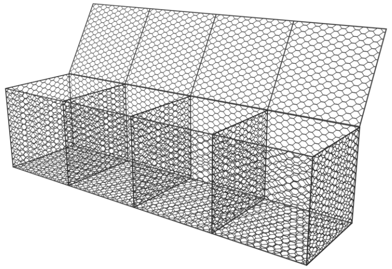
MACMAT R

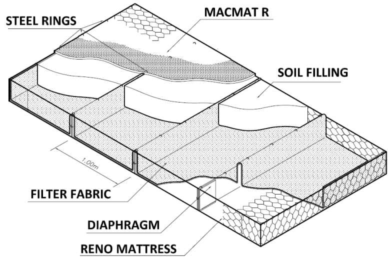
RENO MATTRESS



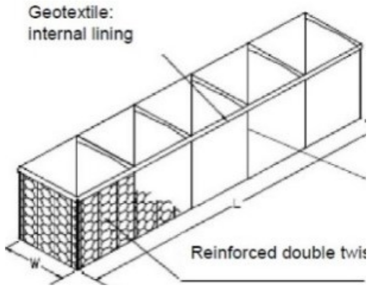
GABIONS



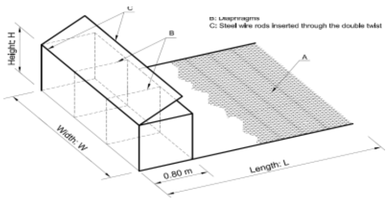
GEOMAC



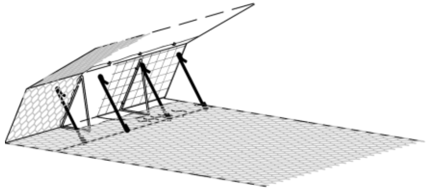
FLEXMAC



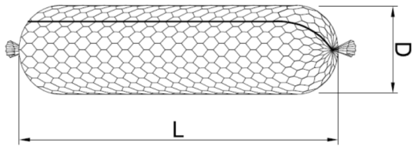
TERRAMESH SYSTEM



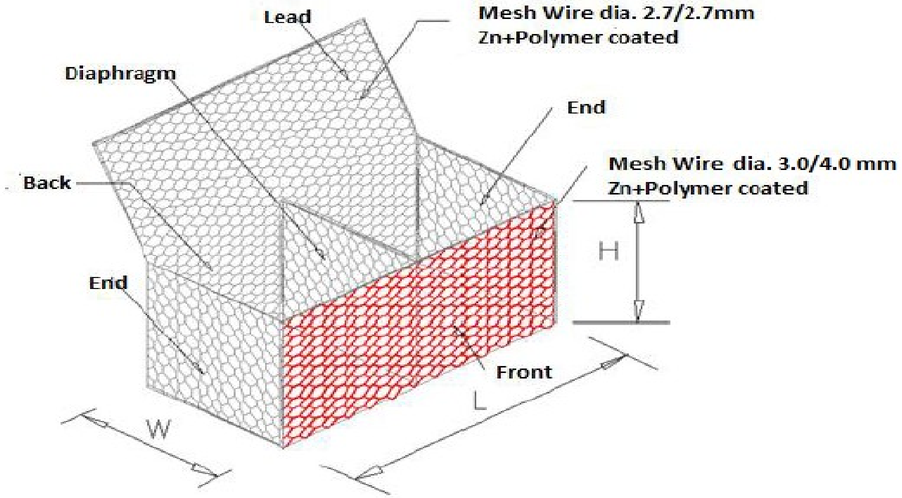
GREEN TERRAMESH



SACK GABIONS



Flexible Solutions & Advantages

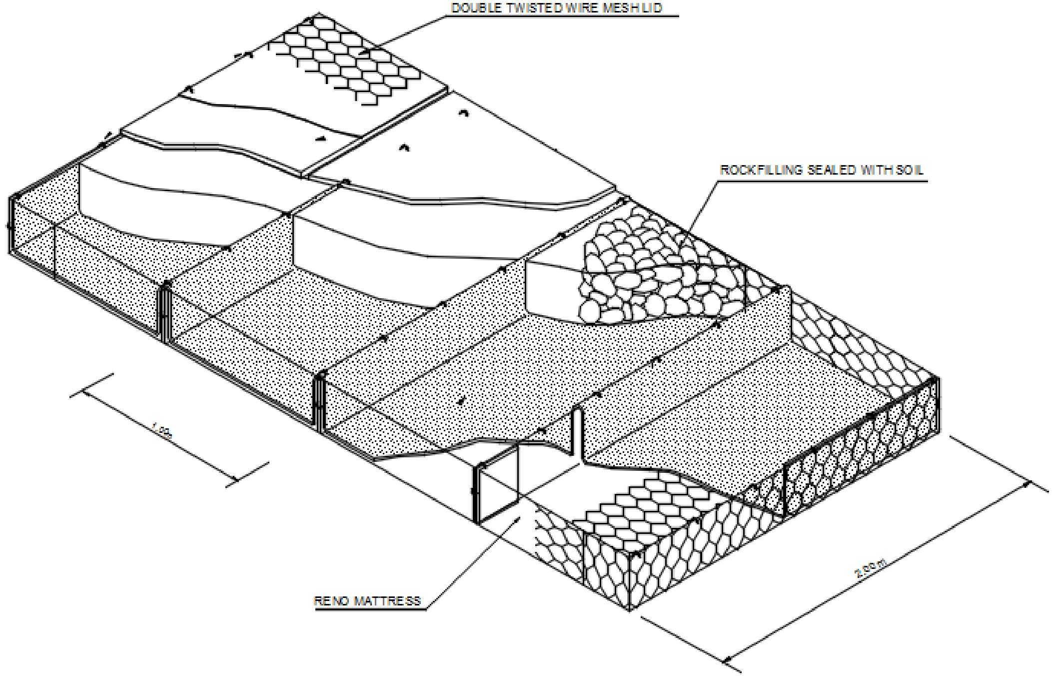


Length (m)	Width (m)	Height (m)	# of cells
2	1	0.5	2
3	1	0.5	3
4	1	0.5	4
1.5	1	1	1
2	1	1	2
3	1	1	3
4	1	1	4

GABIONS

Double twisted wire mesh container of variable size, uniformly partitioned into internal cells, interconnected with similar units, and filled with stone at the project site to form flexible, permeable, monolithic retaining wall structures, channel linings, revetments, and weirs for erosion control.

Flexible Solutions & Advantages



Length (m)	Width (m)	Height (m)
3	3	0.17-0.23-0.3
4	3	0.17-0.23-0.3
5	3	0.17-0.23-0.3
6	3	0.17-0.23-0.3

RENO MATTRESS

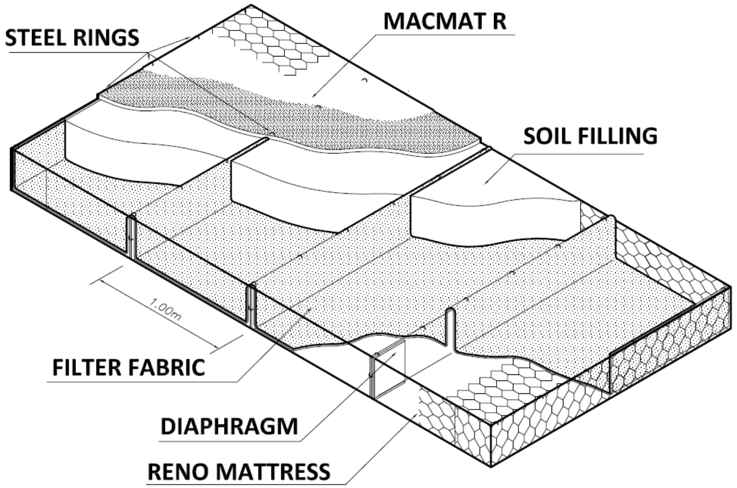
Double twisted wire mesh container uniformly partitioned into internal cells, with relatively small height in relation to the other dimensions, having a smaller mesh opening than the mesh used for the gabions. Used for river bank protection and channel linings.

Flexible Solutions & Advantages

GEOMAC MATTRESS

Double twisted wire mesh container uniformly partitioned into internal cells, with relatively small height in relation to the other dimensions, having a smaller mesh opening than the mesh used for the gabions. Internally lined with a geotextile to allow total or partial filling with vegetative soil. Used for fast revegetation on river banks.

Length (m)	Width (m)	Height (m)
3	3	0.17-0.23-0.3
4	3	0.17-0.23-0.3
5	3	0.17-0.23-0.3
6	3	0.17-0.23-0.3

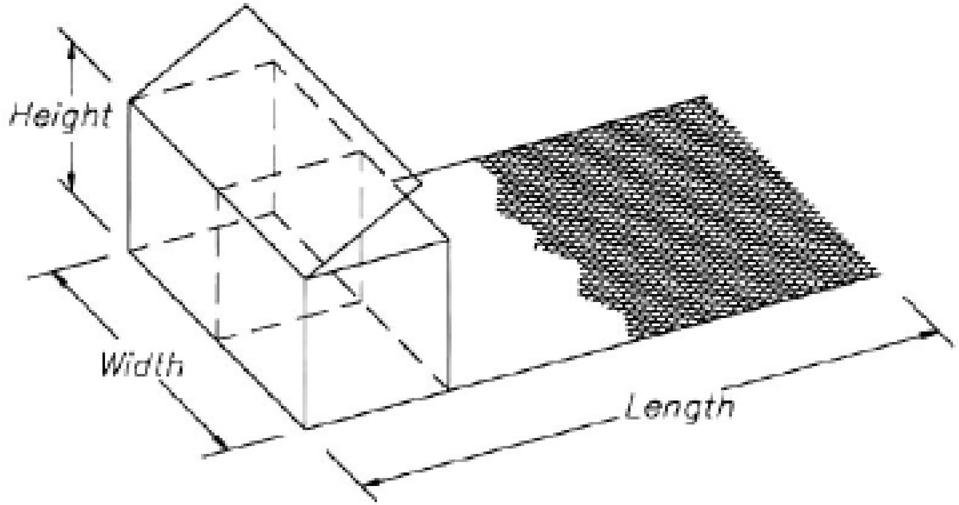


Flexible Solutions & Advantages

TERRAMESH SYSTEM

Pre-assembled wrap-around system made of double twisted hexagonal wire mesh, mesh type 10x12, steel wire Ø 2.7/3.7 mm, Zn-Al and polymer coated. Back panel and diaphragms connected to the facing, forming a confinement to the stone placement on the outer side.

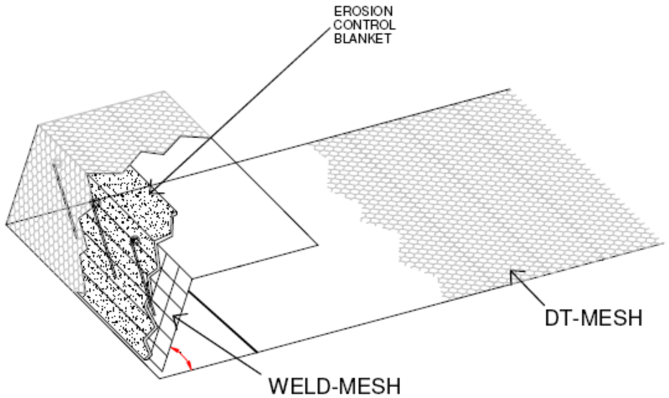
Length (m)	Width (m)	Height (m)
3	2 / 3	1/0.5/0.8
4	2 / 3	1/0.5/0.8
5	2 / 3	1/0.5/0.8
6	2 / 3	1/0.5/0.8



Flexible Solutions & Advantages

GREEN TERRAMESH

Pre-assembled wrap-around system made of double twisted hexagonal wire mesh, mesh type 10x12, steel wire Ø 2.7/3.7 mm or 2.2/3.2mm (light), ZnAl and polymer coated. Erosion mat / coir mat, woven polyester fabric, a welded mesh panel and two steel brackets to pre-form the required slope angle.

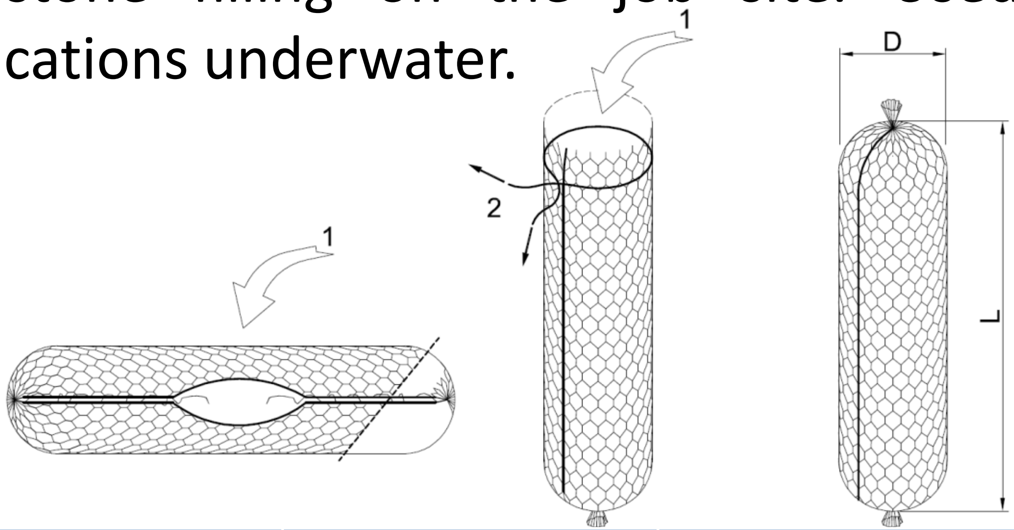


Length (m)		Width (m)	Height (m) / Slope angle
Green Terramesh	Green Terramesh Light	2 / 3	0.63 / 45^0
2.0 to 7.0	2.0 to 7.0		0.76 / 60^0
			0.8 / 65^0
			0.83 / 70^0

Flexible Solutions & Advantages

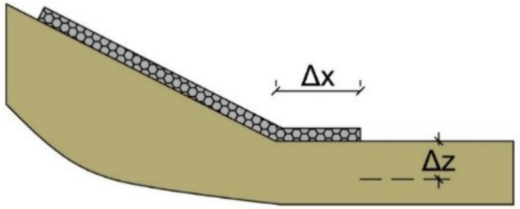
SACK GABIONS

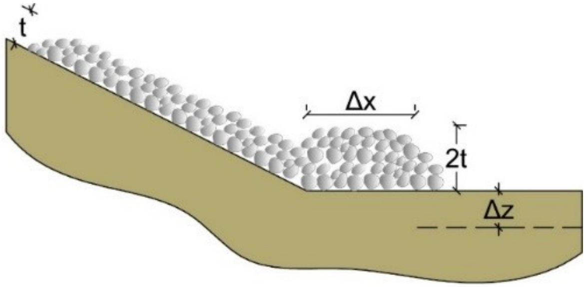
Double twisted steel wire mesh unit of cylindrical shape with a lateral opening to allow the stone filling on the job site. Used in applications underwater.



L=Length (m)	D=Diameter (m)	Volume (m^3)
2	0.96	1.41

RIP RAP VS RENO MATTRESS LININGS [Hard Armor Linings]





✓ **DESIGN:**

- $C_{Shields}$ = 0.047 (for RM three times bigger). => rip rap requires much larger stones and a thicker lining
- larger stones => bigger voids => higher residual velocities underneath => more scour & settlements
- higher thickness => more volume of stones => more transportation costs
- higher thickness => less flow conveyance => need bigger section => more costs in reprofiling

✓ **ENVIRONMENT:**

- higher thickness => low chances of vegetation growth over time
- tests show that rip rap linings produce higher carbon footprint / lesser integration into the environment

✓ **DURABILITY:** questionable/unknown for rip rap (50yrs?) due to additional maintenance required (recharges)

✓ **MATERIAL SUPPLY:** stones shall come from quarry. For RM, stones may be locally available

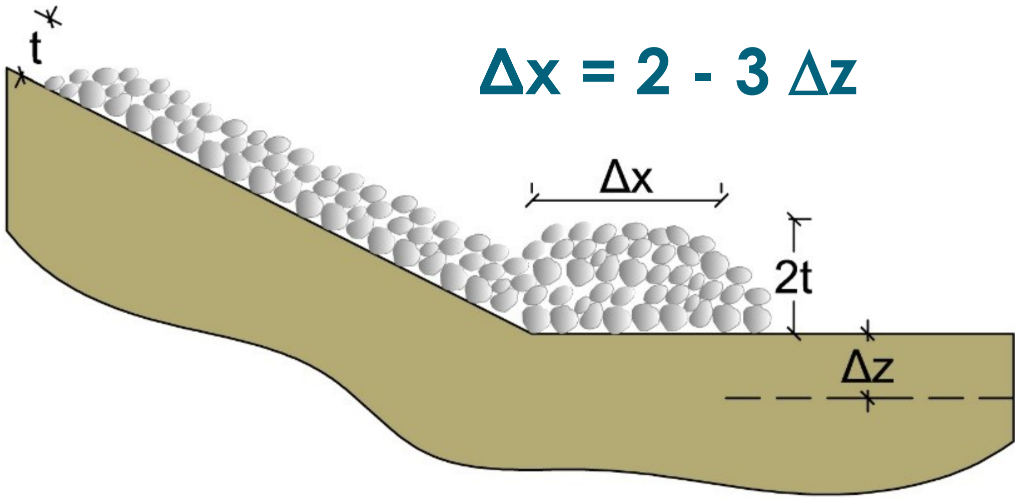
✓ **COST:** cost per linear meter of lining does not include addtl. costs (recharges, extra layer toe, longer apron, etc.)

✓ **OTHERS?**

RIP RAP VS RENO MATTRESS LININGS [Hard Armor Linings]

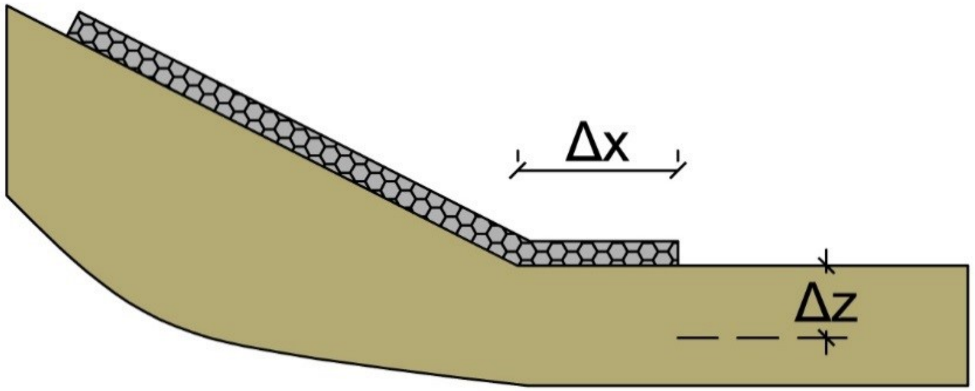
RIP RAP

$\Delta x = 2 - 3\ \Delta z$



RENO MATTRESSES

$\Delta x = 1.5 - 2\ \Delta z$



Stability of rip rap is provided by extending the apron protection by **Δx = 2 - 3Dz**

In addition, due to the loose nature of stone aggregates, the standard practice requires a min thickness **t** = 0.30 m with t/d_{50} = 1.5-2, and the thickness of the revetment at the toe shall be doubled.

Stability of Reno mattresses is provided by extending the apron protection by

Δx = 1.5 - 2Dz

where **Dz** = scour depth.

Design Aspects as per IRC SP 116 & IRC 89

Tractive Force theory

- Erosion is controlled by limiting shear stress exerted by flowing water
- **Channel is stable when actual shear stress is less than allowable shear stress**
- Tractive force theory is used to assess erosive stability
- Exceeding permissible shear stress initiates particle movement
- Progressive increase causes transport of larger soil aggregates

Calculations for Actual Shear Stress from field:

$$t_b = K_1 K_b g_w y S_f$$

Where,

t_b - Design shear stress or actual shear Stress

gw - Unit weight of water

y - Maximum depth of water on revetment in m

Sf - Slope of energy grade line (average riverbed slope)

K1 - slope factor: 1 for horizontal, 0.75 for sloped surfaces

Kb - Bend coefficient (dimensionless explained below)

Design Aspects as per IRC SP 116 & IRC 89

Tractive Force theory

The bend coefficient Kb is used to calculate the increased shear stress on the outside of a bend.

This coefficient ranges from 1.05 to 2.0, depending on the severity of the bend.

The bend coefficient is a function of the radius of curvature Rc divided by the top width of the channel T, as follows:

Kb = 2.0	for 2 ≥ Rc/T
Kb = 2.38-0.206 (Rc/T) + 0.0073(Rc/T) 2	for 10 > Rc/T > 2
Kb = 1.05	for Rc/T ≥ 10

Calculations for allowable/permissible shear stress for a gabion mattress:

tc = Ks Cs (gs-gw)d50

Where,

tc - Permissible shear stress

Cs - Shield for rock-filled revet mattress equal to 0.10

Ks – reduction factor for revert mattress on slope $Ks = \sqrt{1 - \frac{Sin^2 \theta}{Sin^2 \varphi}}$

Design Aspects as per IRC SP 116 & IRC 89

Tractive Force theory

θ bank slope ϕ soil friction angle

gs - Unit weight of the rock fills (22-26 kN/m3)

gw - Unit weight of water

d50- Median diameter of rockfill in mattress

The coefficient Cs is an empirical coefficient developed by Maynord (1995) from test data presented in Simons et al. (1984). Use of Cs = 0.10 got gabion / revet mattress, in which ratio of maximum to minimum stone size ranges from 1.5 to 2.0. Higher Cs may be used when testing carried out such materials.

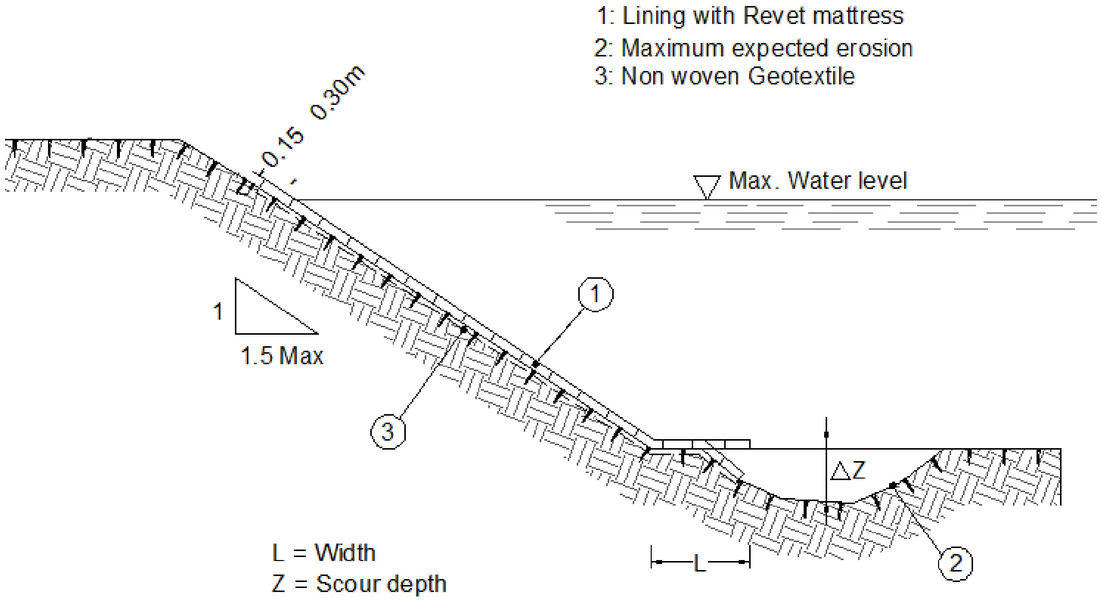
Shear stress on bed shall be less than permissible shear stress.

tb < tc

Design Aspects as per IRC SP 116 & IRC 89

DESIGN OF LAUNCHING APRON

- Launching apron shall be laid at Low Water Level (LWL)
- Apron is designed to launch along the scour slope during erosion
- It should form a protective layer up to the maximum scour depth
- Recommended launching apron slope is 2H : 1V
- Non-woven geotextile filter may be provided below the apron
- Width of the launching apron depends upon the scour depth below HFL.



Typical section of gabion mattress for lining

Design Aspects as per IRC SP 116 & IRC 89

DESIGN OF LAUNCHING APRON

Depth of scour below HFL (D) may be worked out from the following formula.

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

Where,

Q= design discharge in cumecs

f is silt factor. Silt factor (f) may be calculated using the following formula

$$f = 1.76\,(d)^{1/2}$$

Where,

d is mean particle diameter of river material in mm

Maximum scour depth (D_{max}) below HFL= 1.5* Scour depth ($D_{below\ HFL}$).

Maximum Scour depth (D_{max}) below LWL = $(D_{max})_{below\ HFL}$ – (HFL-LWL)

Width of Launching Apron = 1.5 * Maximum Scour depth (D_{max}) below LWL

The best toe protection is obtained by extending the lining for a length of 1.5 to 2 times the expected erosion at the most critical section (L) > 1.5 to 2 Times (ΔZ)

Hydraulic Works | Green Terramesh®, ParaLink®, MacTex™| Guwahati, Assam

Hydraulic Works | Gabions®| Thodupuzha, Kerala

Hydraulic Works | Terramesh ®, ParaLink®, Sack Gabions®, Reno Mattress®| Punalur, Kerala

Hydraulic Works | Gabions, Gabion Mattress & Sack Gabion | Dhakuakhana, Assam

Hydraulic Works | ParaLink®, MacTex™ & Terramesh ® | Valmiki Nagar, Bihar

Hydraulic Works | Gabion Mattress | Narayani River, Nepal

Hydraulic Works | Gabion Mattress | Bagmati River, Nepal

Hydraulic Works | Gabion Mattress | Delhi-Noida Toll Bridge, Uttar Pradesh

Hydraulic Works | Gabion Mattress & Geobags | Rohmoria, Assam

Hydraulic Works | Reno Mattress® , Terramesh ®, ParaLink®, MacTex™ & Strong face Gabion | Varanasi, Uttar Pradesh

Hydraulic Works | Reno Mattress® | Paradip, Odisha

Hydraulic Works | Terramesh system®, ParaLink® & MacTex™ | Ahmedabad, Gujarat

Hydraulic Works | Reno Mattress® | Joshiyara Barrage, Uttarakhand

Hydraulic Works | Reno Mattress®, Terramesh®, ParaLink® & MacTex™ | Varanasi, Uttar Pradesh

Hydraulic Works | Reno Mattress® & MacTex™ | Kalughat, Bihar

Hydraulic Works | Reno Mattress®, ParaLink® & MacTex™ | Patna, Bihar

MACCAFERRI

Jetty bottom reinforcement
in the Arctic zone
Sabetta Port, Russia

Hydraulic Works | RenoMac Plus| Sabetta Port, Russia

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Codal Provisons

- **IS 16014-2024:** Mechanically woven double twisted hexagonal wire mesh gabions, rivet mattress, rockfall netting and other products for civil engineering purposes (Galvanised Steel wire or Galvanised Steel wire with polymer coating)- Specifications
- **IRC 89-2019** - River Training and Control Works for Bridges
- **MoRT&H Section 2500:** It is dedicated to River Training and Protection works and has specifications and guidelines on the flexible structures like gabions, mattresses with technical specifications
- **MoRT&H Section 700:** It describes the specification for use of geosynthetic reinforcement in erosion control works
- **IRC SP 116-2018:** Guidelines for Design and Installation of Gabion structure
- **IRC SP 113: 2018** Guidelines on Flood Disaster Mitigation for Highway Engineers
- **IRC 34-2011:** Recommendations for road construction in areas affected by water logging, flooding and Salts Infestation have introduced some innovative solutions for subsurface drainage, capillary cut-offs etc.
- **IRC 56-2011:** Recommended Practice for treatment of embankment and roadside slope for erosion
- **Central Water Commission Guidelines:** Define the suitability of various flexible structures for flood protection and river training works
- **GFCC Guidelines:** Guidelines for use of Geotextiles/ Geotextile bags/ Geotextile tubes in construction of flood management works

Key Takeaways

- Climate resilience requires system-level thinking
- Sustainable riverbank protection enhances dam safety
- Flexible, nature-based, and lifecycle-oriented systems perform better
- Operations and maintenance are as critical as initial design

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Conclusions

- Sustainable infrastructure is a balance of:
  - Safety
  - Resilience
  - Environmental responsibility
- Riverbank protection works play a vital role in climate-resilient dams and hydropower projects
- Integrated planning leads to long-term sustainability


Thank You