River Training/Bank Protection

A definition of **river training** can be as follows:

"all engineering works constructed in a river which are required to guide and confirm the flow to the river channel and to regulate the river bed and bank configuration for effective and safe movement of floods (water and sediment)". Stabilizing and training the river along a certain alignment with a suitable waterway is, therefore, the first and foremost aim of river training.

Objectives of River Training:

- Safe and quick passage of high flood
- Efficient transport of sediment load
- Make river course stable and prevent bank erosion
- Provide sufficient draft for navigation, and
- Prevent outflanking (bypassing) of a structure by directing the flow in a defined stretch of the river

River training structures can be classified into two main categories:

- Transversal protection structures – active structures in reducing/redirecting the erosive forces
- Longitudinal protection structures – passive structures in preventing erosion (absorbing force)

River Training/Bank Protection

Hardcore and Softcore Bank Protective Works

Hardcore protective works rely on rigid, man-made structures to resist the erosion, while the softcore (also called Bio-engineering or Nature-based Solutions) works utilize the natural materials and vegetation to absorb water energy and stabilize the soil.

Softcore protective works are also called green infrastructure because they are living, bio-degradable and reduces carbon emission. These works tackle climate change in two major ways: by **slashing the emissions** created during construction and by **actively absorbing carbon** from the atmosphere.

The major limitation of soft-core and green riverbank protection is its inability to withstand high-velocity water, extreme wave action, or immediate, severe erosive forces (as time is required for the plants to grow).

Because these solutions rely on plants growing and roots establishing to gain structural strength, they are highly vulnerable during their initial phase and cannot match the raw, immediate structural strength of concrete or steel.

River Training/Bank Protection

Transverse protection structures

These structures are installed perpendicular to the water course and are used in order to reduce (redirecting) the water velocity and protect the river bed and banks from erosion.

These structures include Spurs (also called groynes), Sills, Screen, Bandals, Porcupines, etc. are some examples.

Longitudinal protection structures

Longitudinal protection structures are installed on river banks parallel to the river course, generally with the aim of protecting adjoining bank areas from inundation, erosion, and river meandering. They are usually constructed on natural banks and extend for a considerable distance (both upstream and downstream).

These structures include Levees or earth fill embankments (also called dykes), concrete embankments, Guide banks, Revetments and Rock riprap, sheet piles, etc.

River training works consist of *structures* and various types of *earth works*. They comprise of embankments, dredging and reclamation for channels and cut-offs.

River training structures, apart from various types of earth works, are basically achieved by the following structures:

Groyne/Spur





Sedimentation



Revetment





River Training

- spur-dikes, spurs, groynes – transverse structures
- longitudinal dikes, depending on their function also called guide banks or guide bunds
- bank protection (revetments, hard points)

Spurs

A spur or groyne is a structure built across the flow from a river bank into the river. This form of river training works perform one or more functions such as:

- training the river along the desired course to reduce the concentration of flow at the point of attack,
- creating a slack flow or slack zone (region of reduced velocity) for silting up the area, and
- protecting the bank by keeping the flow away from it.

Spurs help train a river to flow along a desired course by preventing erosion of the bank and encouraging flow along a channel with a more desirable width and alignment. They are also used to control natural meandering at a river bend (shortening the length for navigation), to channelize wide rivers, and to convert poorly defined streams into well defined channels. The spurs create a zone of slack flow which encourages silting up in the region of the spur to create a natural bank. They generally protect the riparian environment (habitat and physical diversity).

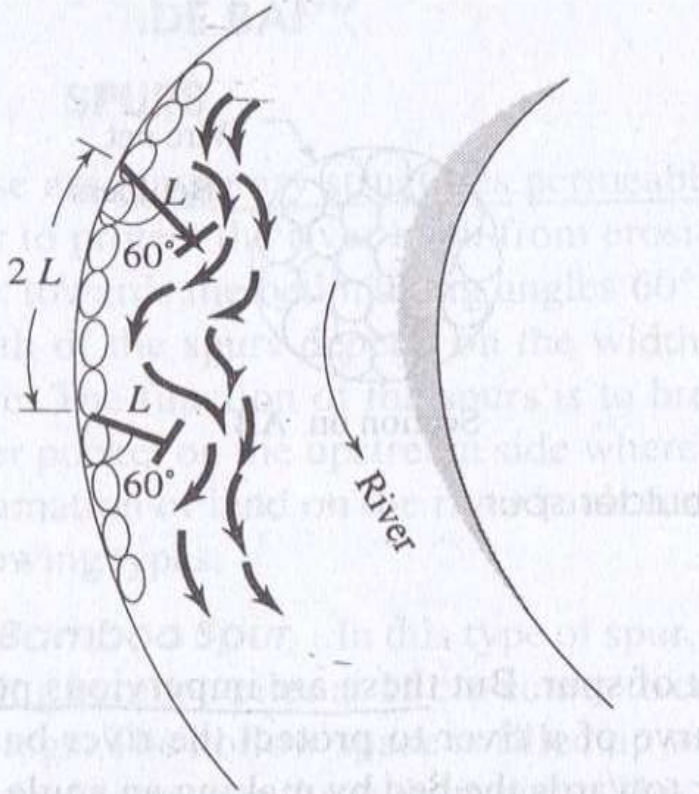


Fig: Attracting groyne

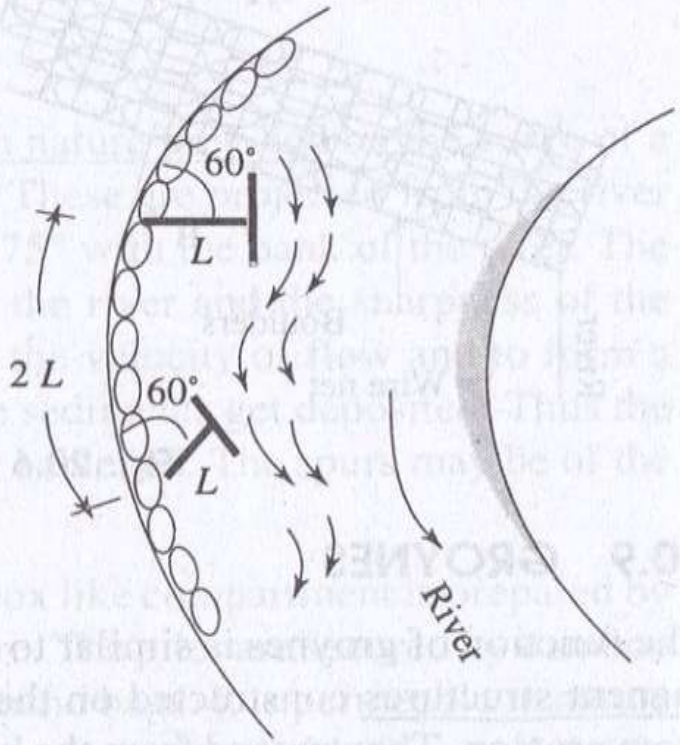
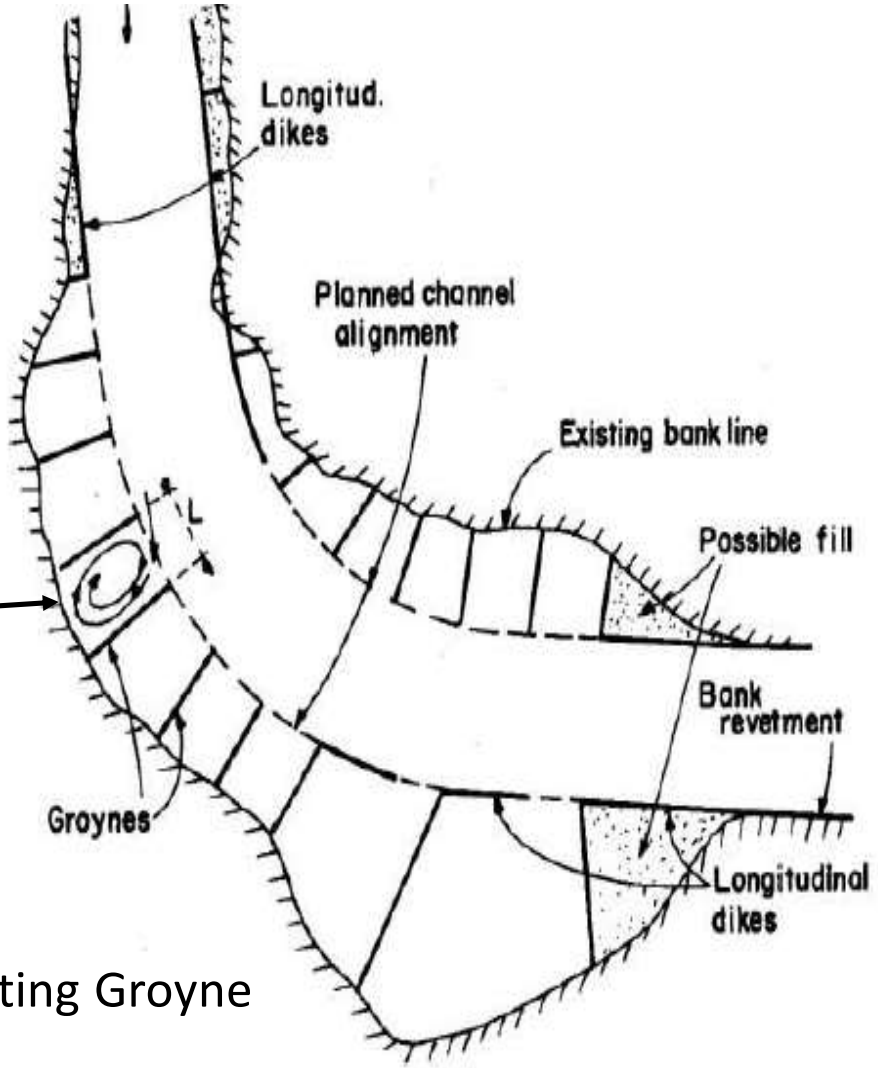


Fig: Repelling groyne

Slack zone



Deflecting Groyne

River Training

At least two to five structures are typically placed in series along straight or convex bank lines where the flow lines are roughly parallel to the bank.

Spurs can be made from many materials including stone, or in bamboo ‘cages’; tree trunks and branches; concrete; or any material that is not easily detached by the river and is strong enough to withstand the flow and the impacts of debris.

They can be categorized/classified on the basis of permeability, submergence, orientation, and the shape of the head.

Permeability

Impermeable spurs do not permit appreciable flow through them whereas *permeable* ones permit restricted flow through them. An impermeable spur blocks and deflects the river flow, while a permeable spur allows water to pass through but reduces the water velocity.

Impermeable spurs may be constructed of a core of sand or sand and gravel or soil as available in the river bed and protected on the sides and top by a strong armour of stone pitching or concrete blocks.

Permeable spurs usually consist of timber stakes or piles driven for depths slightly below the anticipated deepest scour and joined together to form a framework by other timber pieces and the space in between filled up with brush wood or branches of trees. As the permeable spurs slow down the current, silt deposition is induced.

Figure 45: Permeable and impermeable spurs

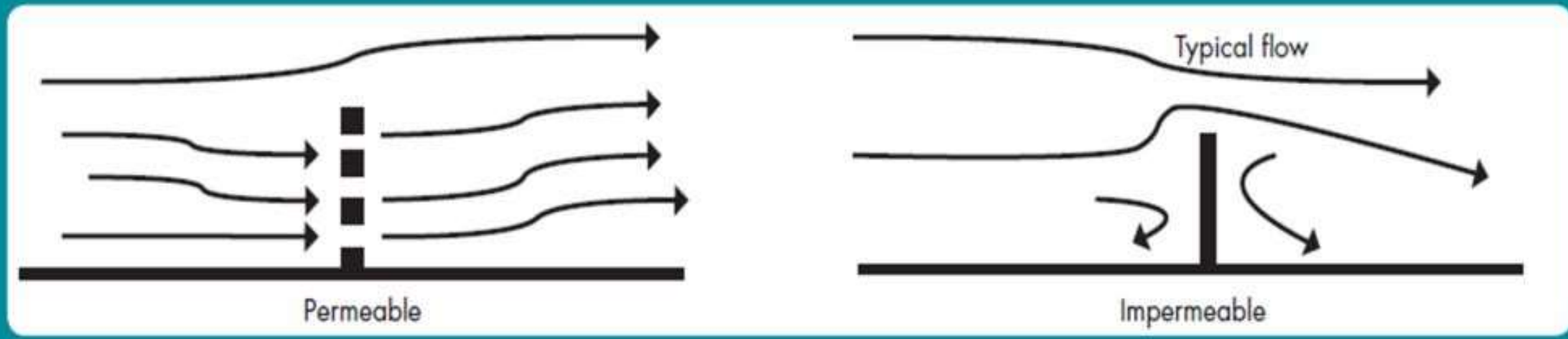
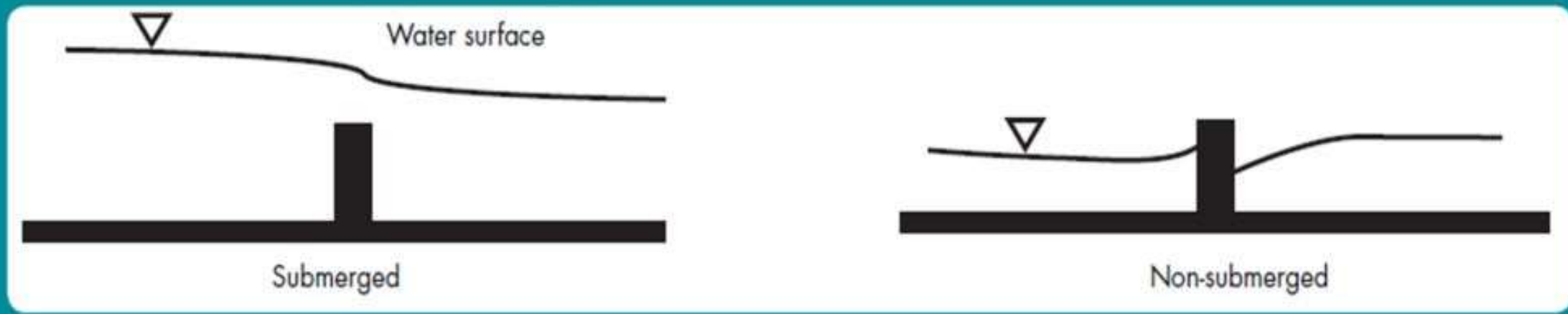


Figure 46: Submerged and non-submerged spurs

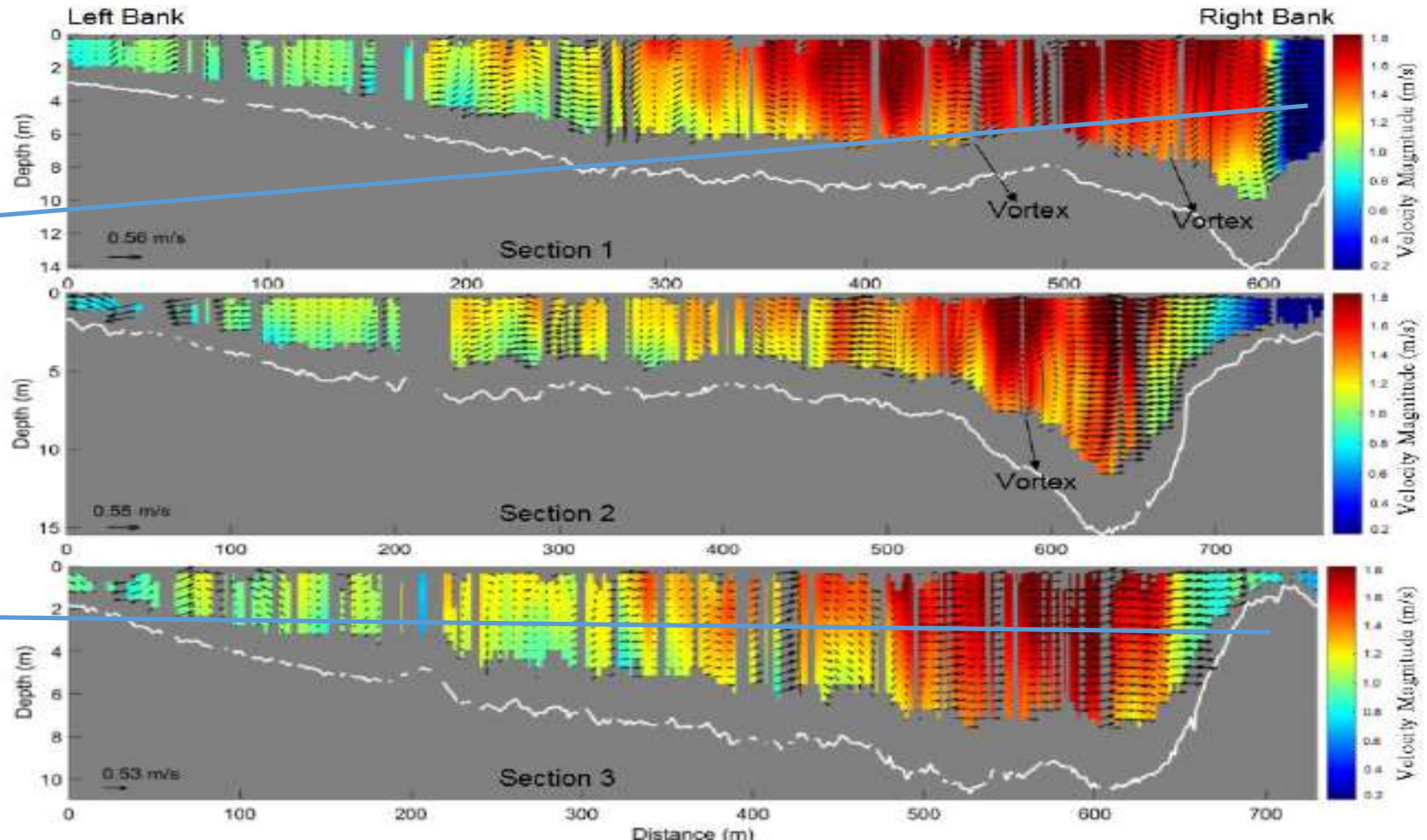




Permeable Groyne

Bank Erosion

Deposition in right bank with decrease in velocity (note change in depth and velocity from right bank)



River Training

Orientation/Layout

Spurs or Groynes are much more effective when constructed in series as they create a pool of nearly still water between them which resists the current and gradually accumulates silt forming a permanent bank line in course of time.

Spurs can be *attracting, deflecting, or repelling* according to their inclination (orientation) as shown in figure. An attracting spur points downstream and attracts the flow towards its head and thus to the bank, maintaining a deep current close to the bank.

A deflecting spur (set perpendicular to the bank line) changes the direction of the flow without repelling it and creates a slack zone behind.

A repelling spur points upstream and diverts the flow away from itself. The repelling spurs are constructed with an inclination upstream which varies from 10^0 to 60^0 to the line normal to the bank.

Shape of Head

Several types of groyne heads are constructed worldwide such as I-head, L-head and T-head, Hockey shaped, Circular etc. in accordance to various river environments. Among these, I-head groynes are more investigated and common. T-head, L- head and Hockey head groynes generally lead to increased sediment deposit, lesser scour at the groyne head, better bank protection and richer habitat for aquatic life.

Figure 47: Different orientation of spurs

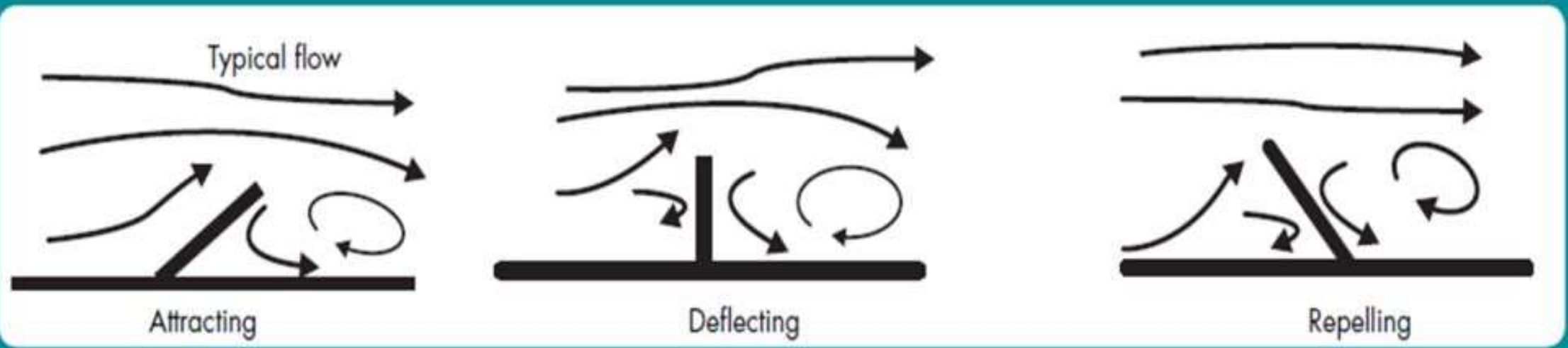


Figure 48: Different shapes of spur

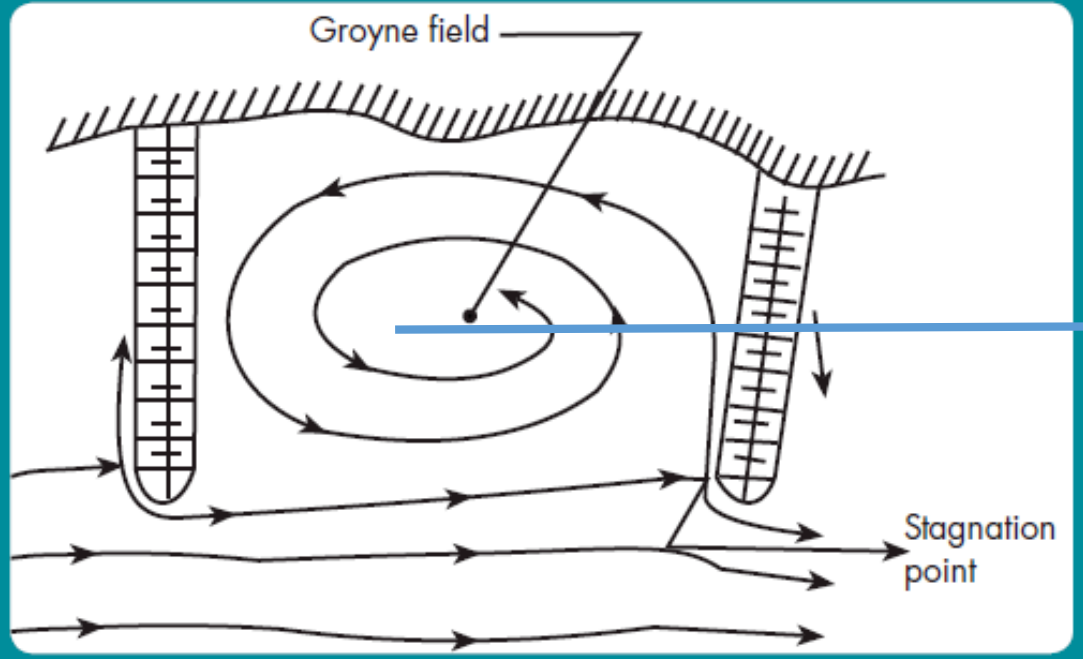


Design Considerations:

Length

The length of groynes depends upon the position of the original bank line and the designed normal line of the trained river channel. Hence, it would be better to construct shorter ones in the beginning and extend them gradually as silting between them proceeds. Shorter and temporary spurs constructed between long ones are helpful in inducing silt deposition.

Figure 49: Formation of eddy between two spurs



Source: HMGN 1990

River Training

As a general rule, the length of a spur should be no more than 1/5 the river width and no less than 2.5 times the scour depth.

The scour depth is given by:

$d_s = 1.35 (q^2/f)^{1/3}$

where: d_s = the normal scour depth below high flood level (HFL), q = discharge in m^3/sec per meter width, and f = Lacey's silt factor, which depends upon the grain size of the river bed material.

Spacing

The primary factor governing the spacing between adjacent spurs/groynes is their lengths. Generally, a spacing of 2 to 2.5 times the length of groynes is adopted.

Number of spurs

The number of spurs depends on the length of stream bank to be protected and the calculated space between spurs.

Two to five structures are typically placed in series along straight or convex bank lines where the flow lines are roughly parallel to the bank.

River Training

Guide Bank

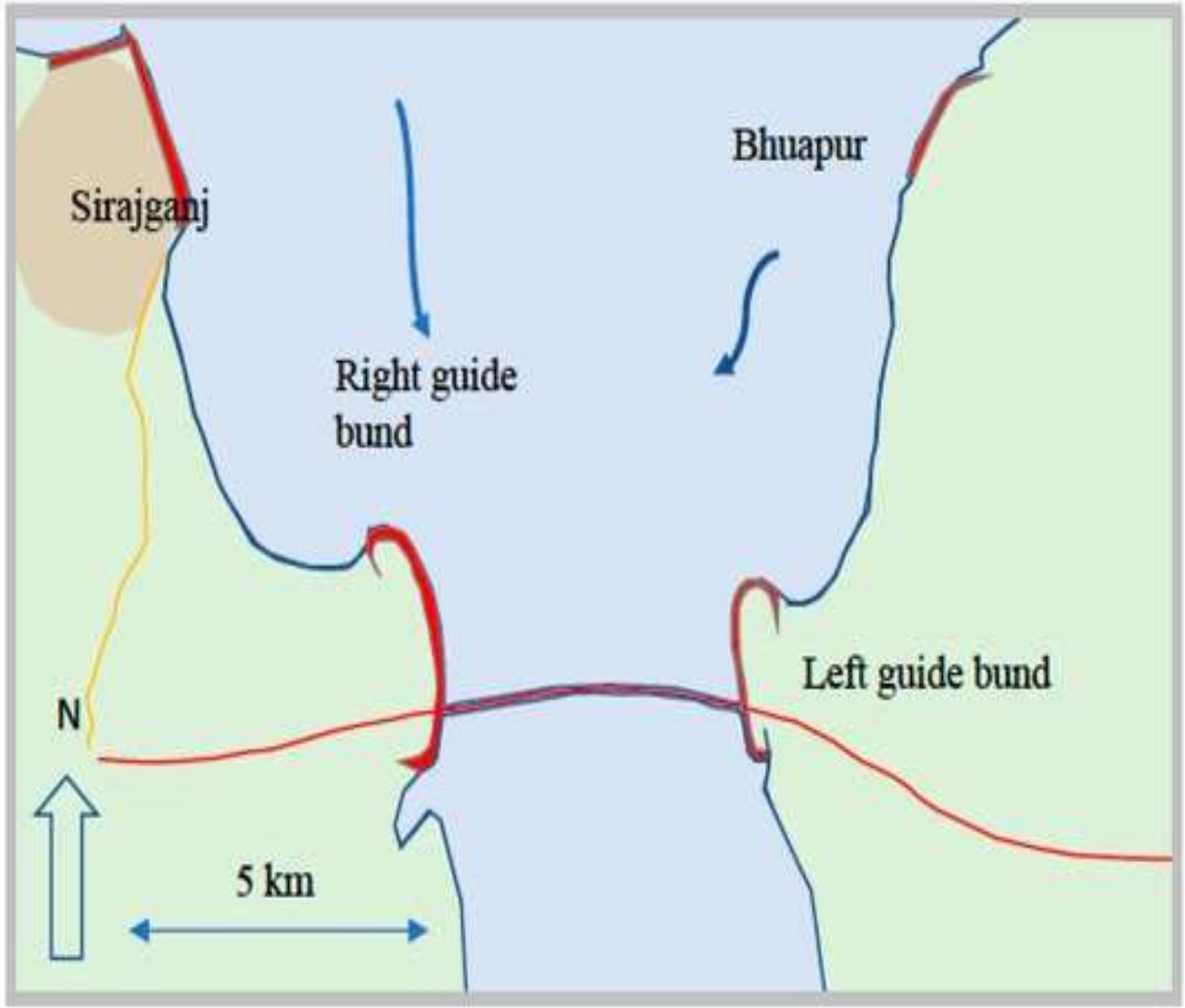
Alluvial rivers in flood plains spread over a very large area during floods and it would be very costly to provide bridges or any other structure across the entire natural spread. It is necessary to narrow down and restrict its course to flow axially through the diversion structure. Moreover, it is also used to reduce or eliminate local scour at the embankment and the river bank.

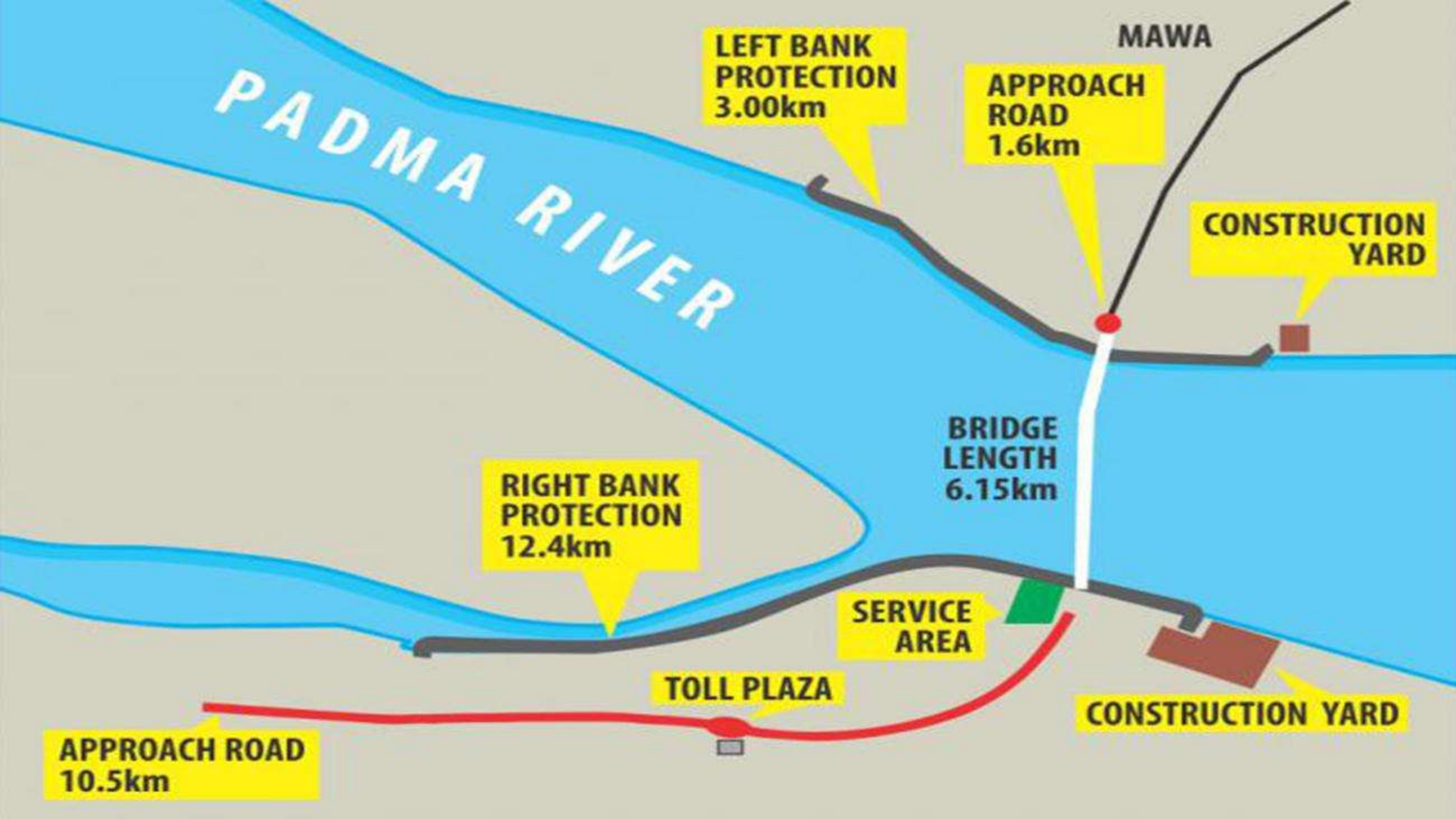
Guide bunds are provided for the purpose of guiding the river flow past the diversion structure without causing damage to it and its approaches. They are constructed on both on the upstream and downstream of the structure and on one or both the flanks as required.

Two guide banks are generally required when the waterway opening is in the middle of a wide flood plain or is a braided stream where the direction of the main flow can shift from side to side. A single guide bank may be sufficient at a location where the river is confined to one side of a valley and it is possible to take advantage of a natural non-erodible bank such as a hard rock exposed surface.

Length

The length of the guide bund on the upstream is generally kept as 1.0 to 1.5L where L is the width between the abutments of the diversion structure. In order to avoid heavy river action on the guide bunds, it is desirable to limit the obliquity of flow to the river axis not more than 30^0. The length of the downstream guide bund is kept as 0.25L to 0.4L.


Sirajganj
Bhuapur
Right guide bund
Left guide bund
N
5 km


PADMA RIVER
LEFT BANK PROTECTION 3.00km
APPROACH ROAD 1.6km
MAWA
CONSTRUCTION YARD
BRIDGE LENGTH 6.15km
RIGHT BANK PROTECTION 12.4km
SERVICE AREA
TOLL PLAZA
CONSTRUCTION YARD
APPROACH ROAD 10.5km

River Training

Curved head and tail

The upstream curved head guides the flow smoothly and axially to the diversion structure keeping the end spans active. The downstream curved tail provides a smooth exit of flow from the structure.

From the hydraulic model tests conducted for a number of projects over the past years, it has been found that a radius of the curved head equal to 0.4 to 0.5 times the width of the diversion structure between the abutments usually provides satisfactory performance. The radius of the curved tail generally ranges from 0.3 to 0.5 times the radius of the curved head.

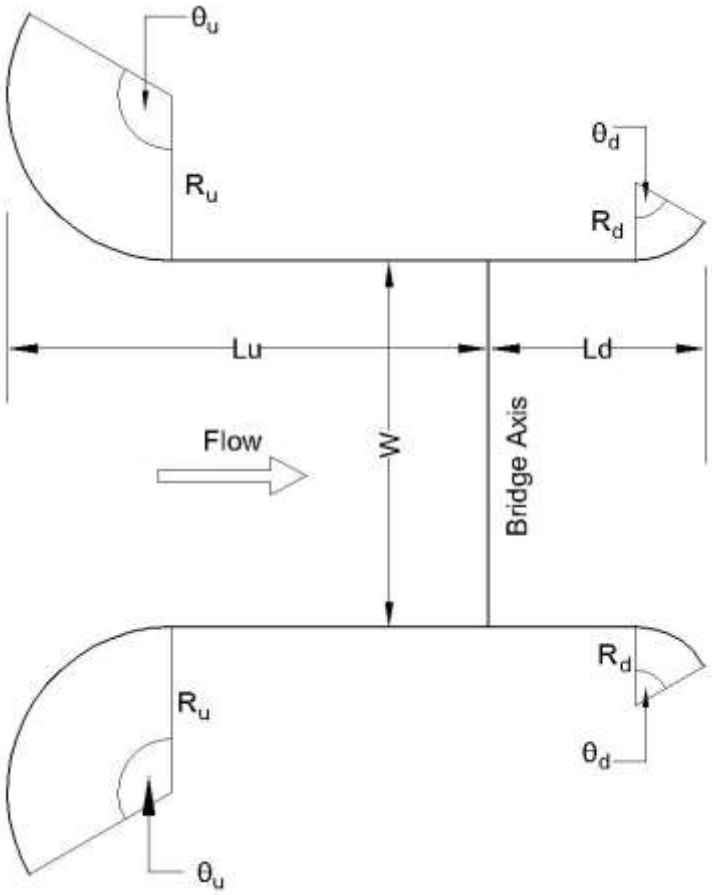
According to the river curvature, the angle of sweep of curved upstream head ranges from 120^0 to 145^0. The angle for the curved tail usually varies from 45^0 to 60^0.

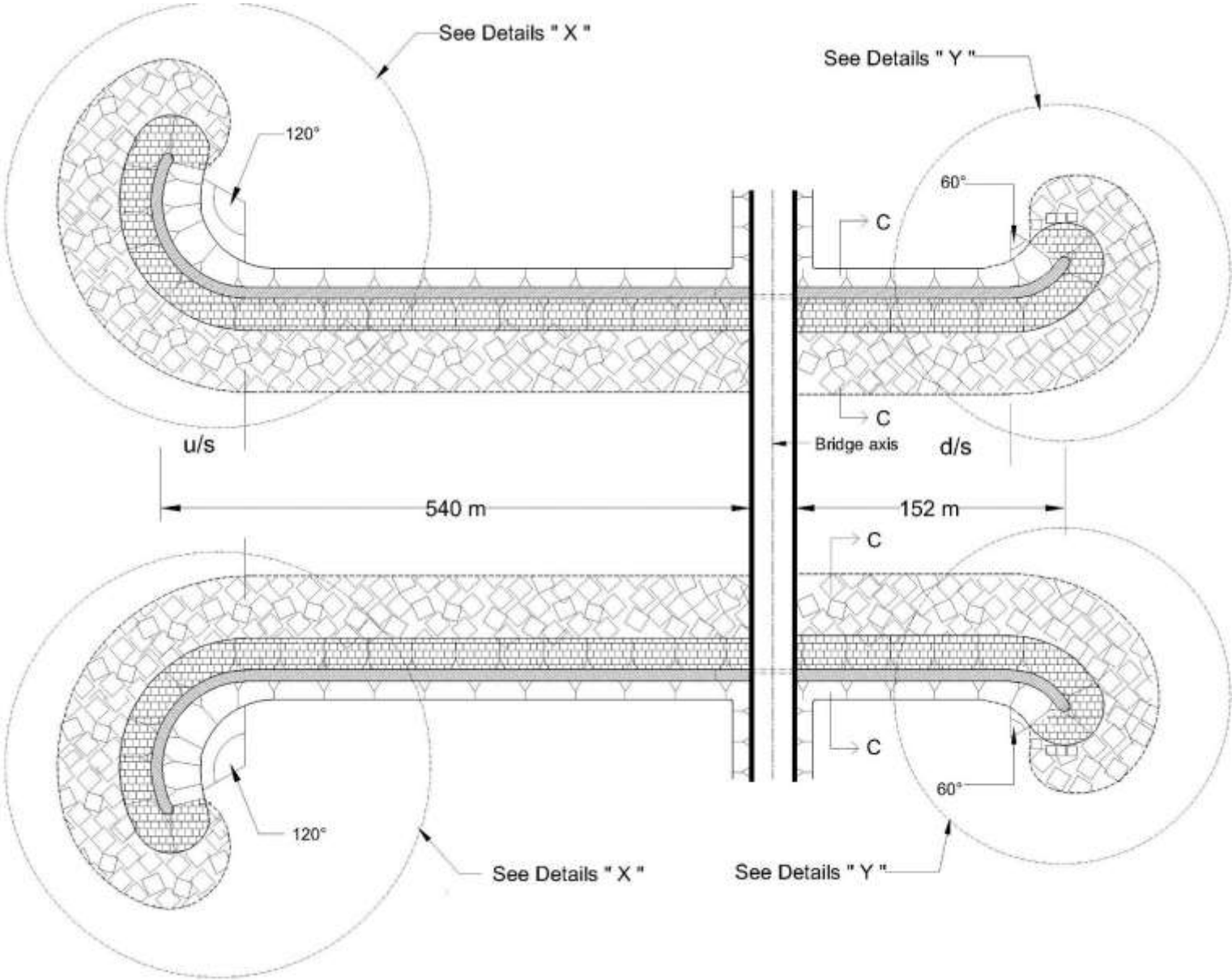
Top width

At the formation level, the width of the shank of guide bunds is generally kept 6 to 9 m to permit carriage of material and vehicles for inspection.

Launching apron

A launching apron is a flexible stone cover placed on the bed of the river which settles into the scouring area as scouring takes place and covers the base and side of the scour hole, preventing it from developing further.

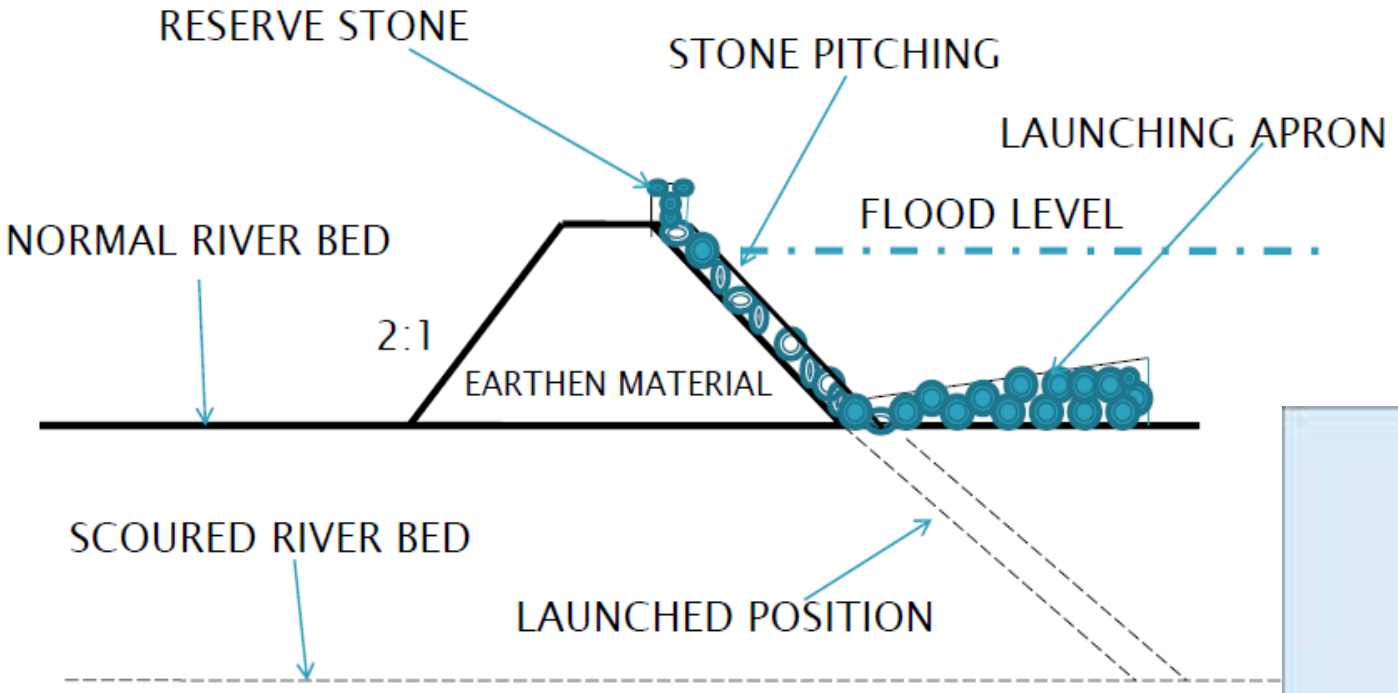


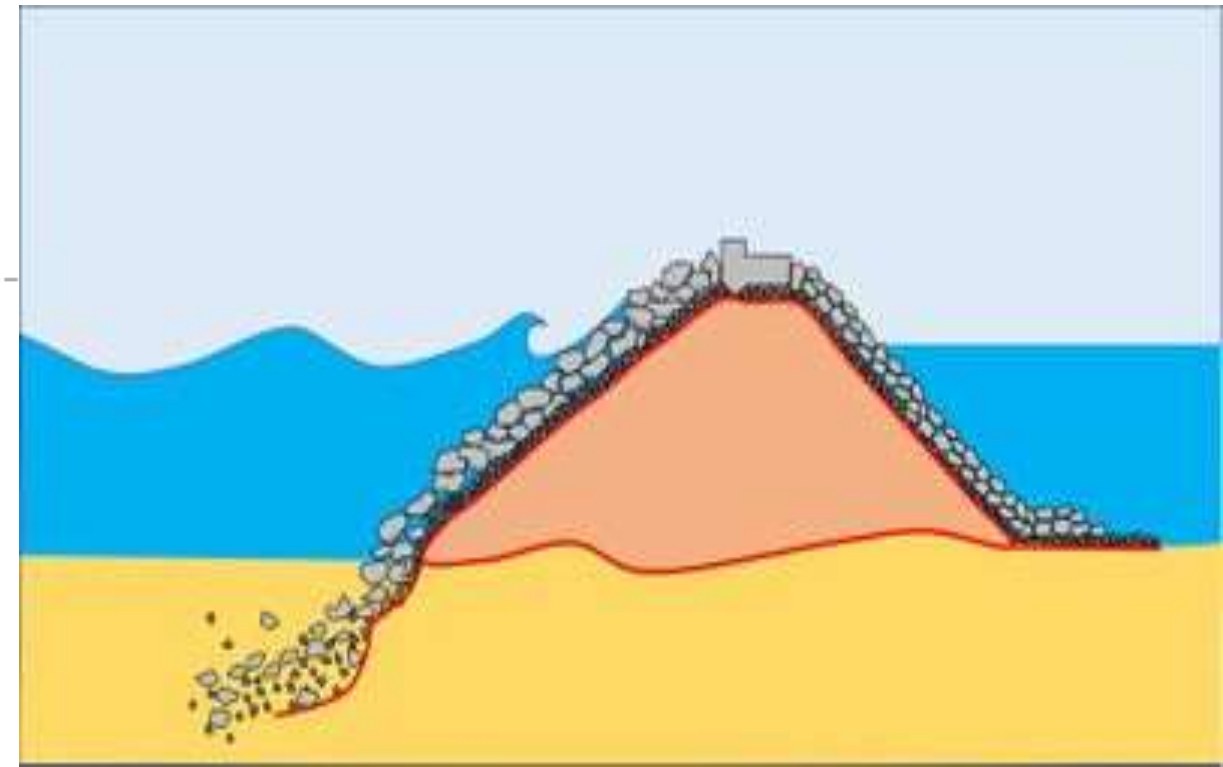


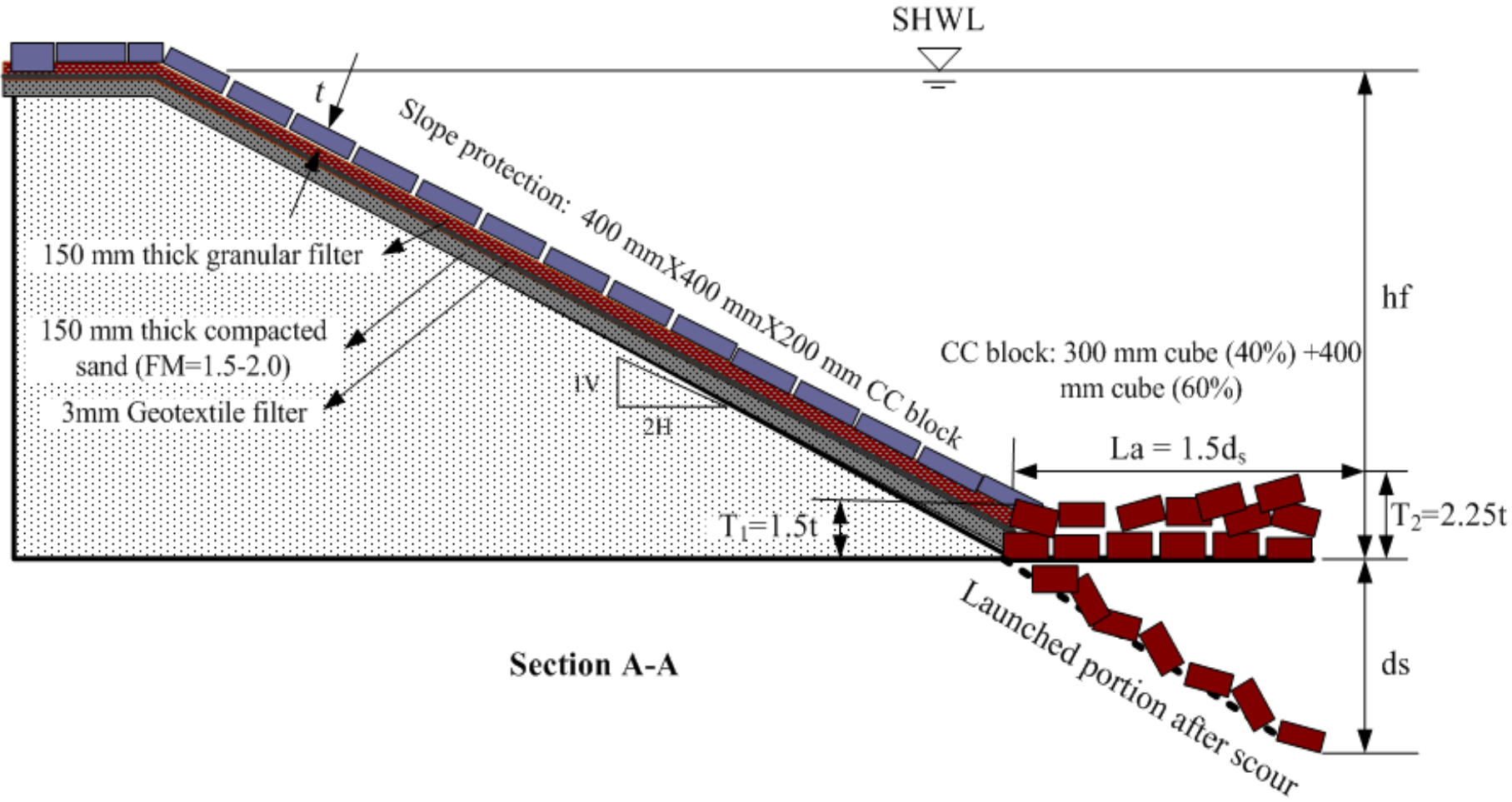
Guide bank on Arial Khan river at Madaripur Sadar

River Training

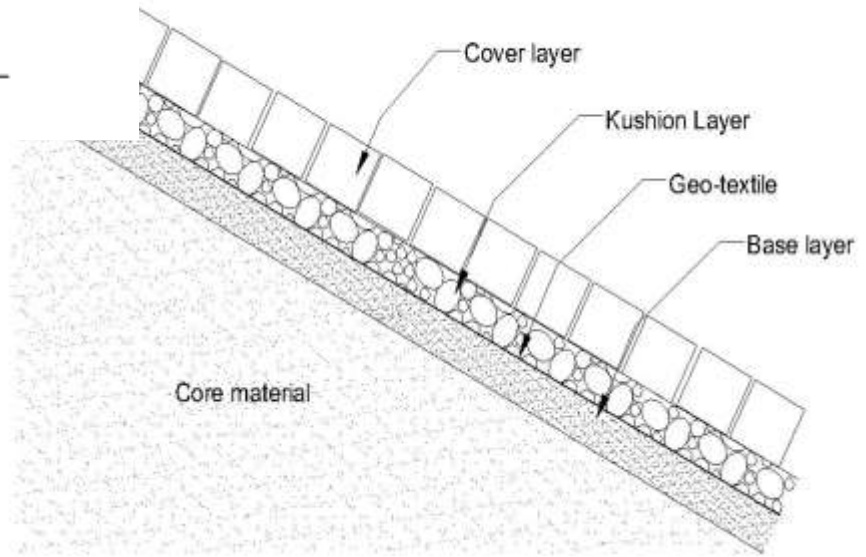
Guide Bank






SHWL
t
Slope protection: 400 mmX400 mmX200 mm CC block
150 mm thick granular filter
150 mm thick compacted sand (FM=1.5-2.0)
3mm Geotextile filter
1V
2H
CC block: 300 mm cube (40%) +400 mm cube (60%)
hf
La = 1.5d_s
T_2=2.25t
T_1=1.5t
ds
Launched portion after scour

Section A-A


Cover layer
Kushion Layer
Geo-textile
Base layer
Core material

River Training

Porcupines

Porcupines are a form of permeable structure (both transverse and longitudinal) designed to reduce flow and trap sediment. They have pole-like projections in all directions, resembling a porcupine. They are generally used for river bank and bed protection and to trap sediment.

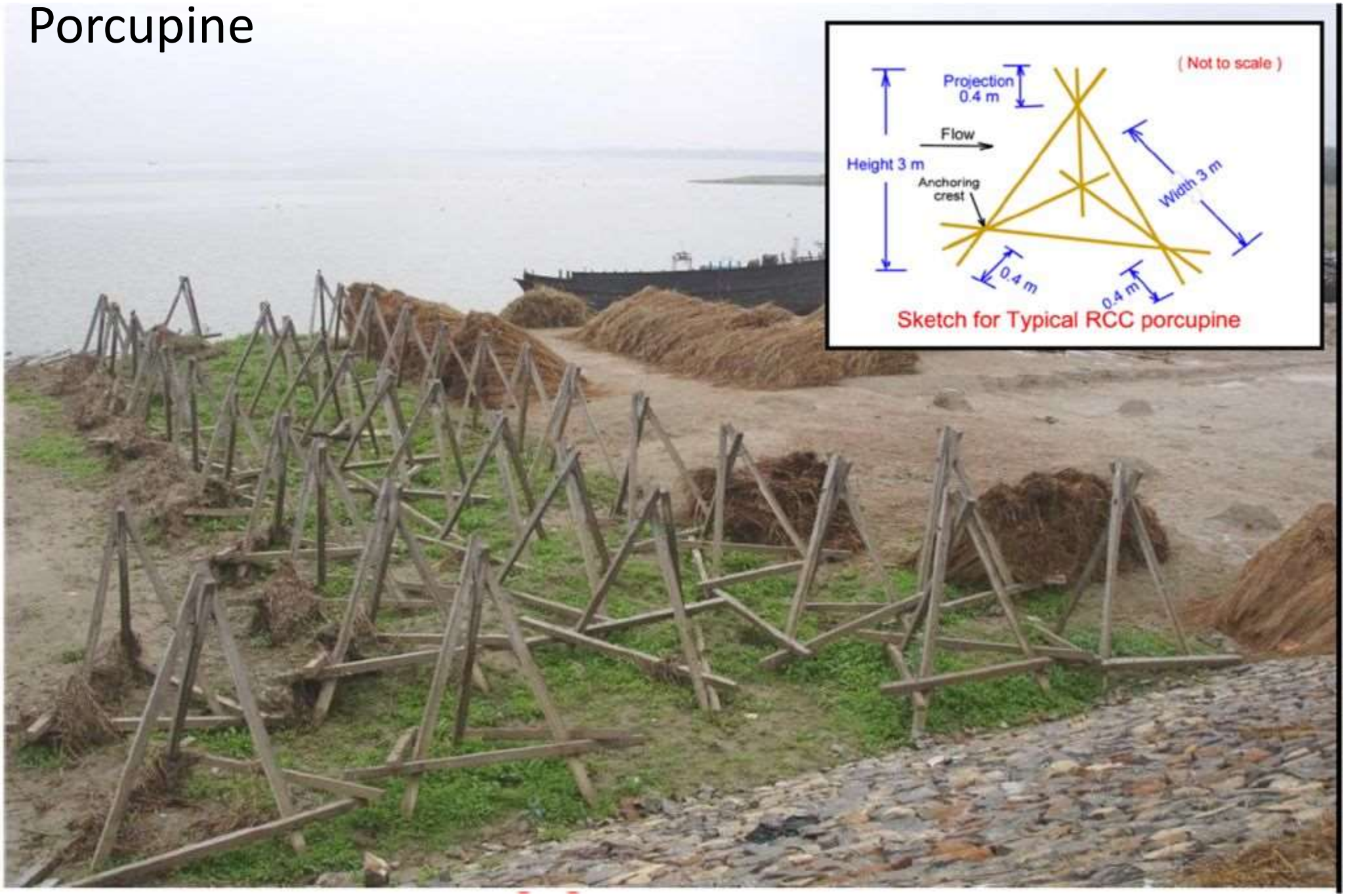
Porcupines can be used in a line forming a spur into a river, as silting aprons for larger spurs, and in a longitudinal line along an embankment. Originally such devices were made of timber or bamboo, but these have a limited lifespan. The use of wooden and bamboo porcupines combined with vegetation form a green wall.

There are two kinds of concrete porcupine in common use: reinforced cement (RCC) and pre-stressed cement (PSC). Porcupines can be constructed in two shapes, tetrahedral and prismatic.

Tetrahedral porcupines - the most common shape is formed by assembling six concrete struts of the same length in a tetrahedral pattern (figure). Individual struts are bolted together, projecting beyond the joint. The size of a porcupine is denoted by the length of the individual struts, for example a 2 m porcupine or 3 m porcupine and have a cross-section of 10 x 10 cm.

Prismatic porcupines are made with nine concrete struts joined in the form of a prism (figure). Two end triangles are formed first and then joined together with three struts placed at the vertices.

Porcupine


(Not to scale)
Projection
0.4 m
Flow
Height 3 m
Anchoring
crest
Width 3 m
0.4 m
0.4 m
Sketch for Typical RCC porcupine



Porcupines

Figure 52: Tetrahedral porcupine (dimensions in metres, shown here for a 3 m porcupine)

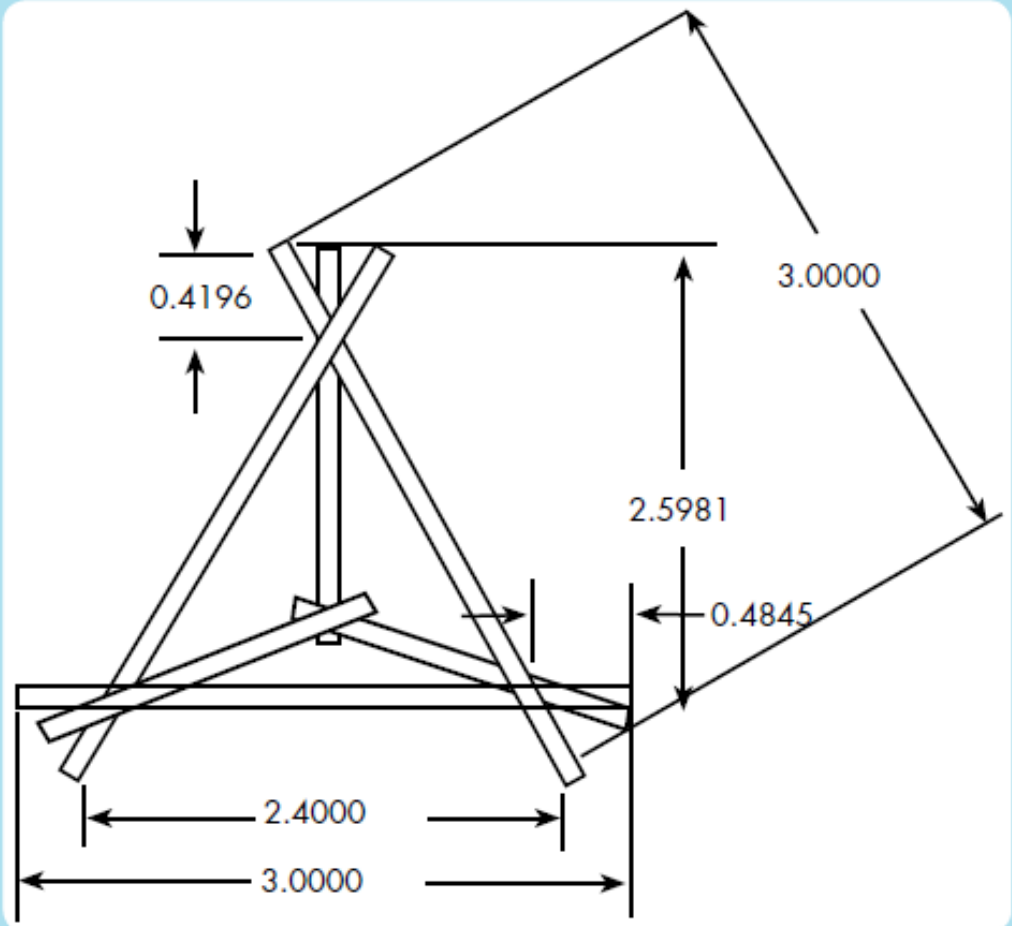


Figure 53: Prismatic porcupine

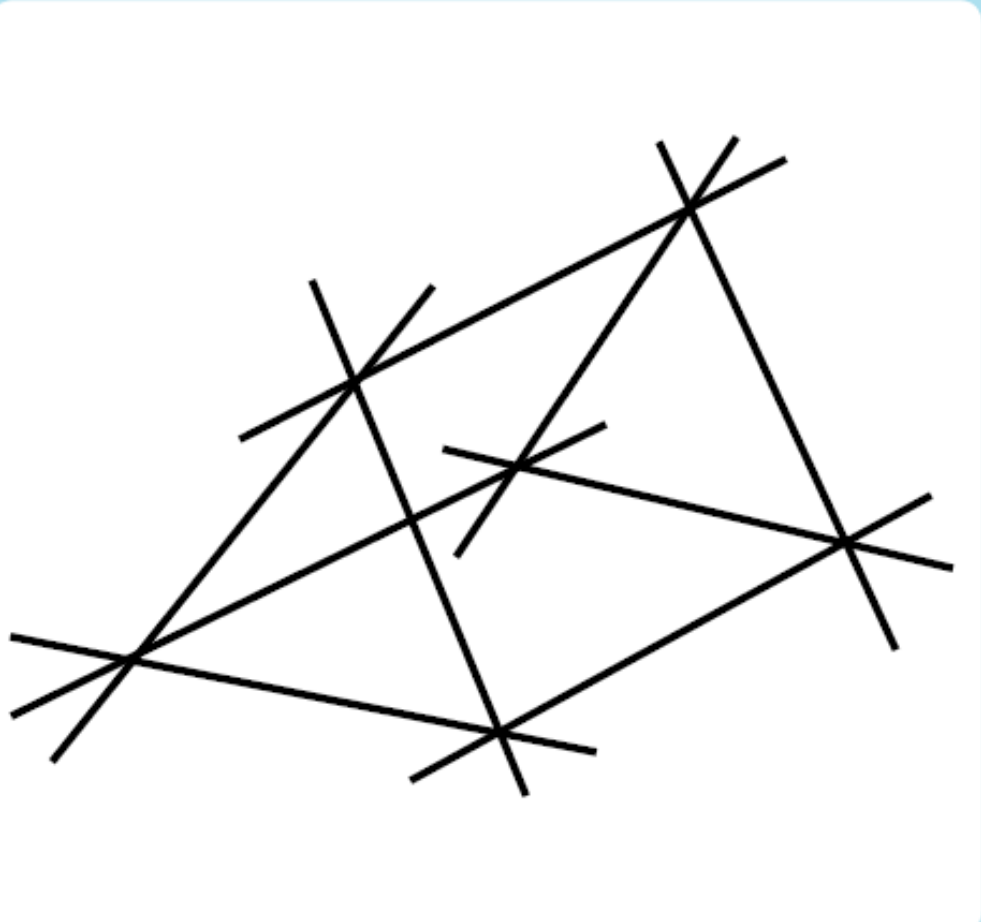
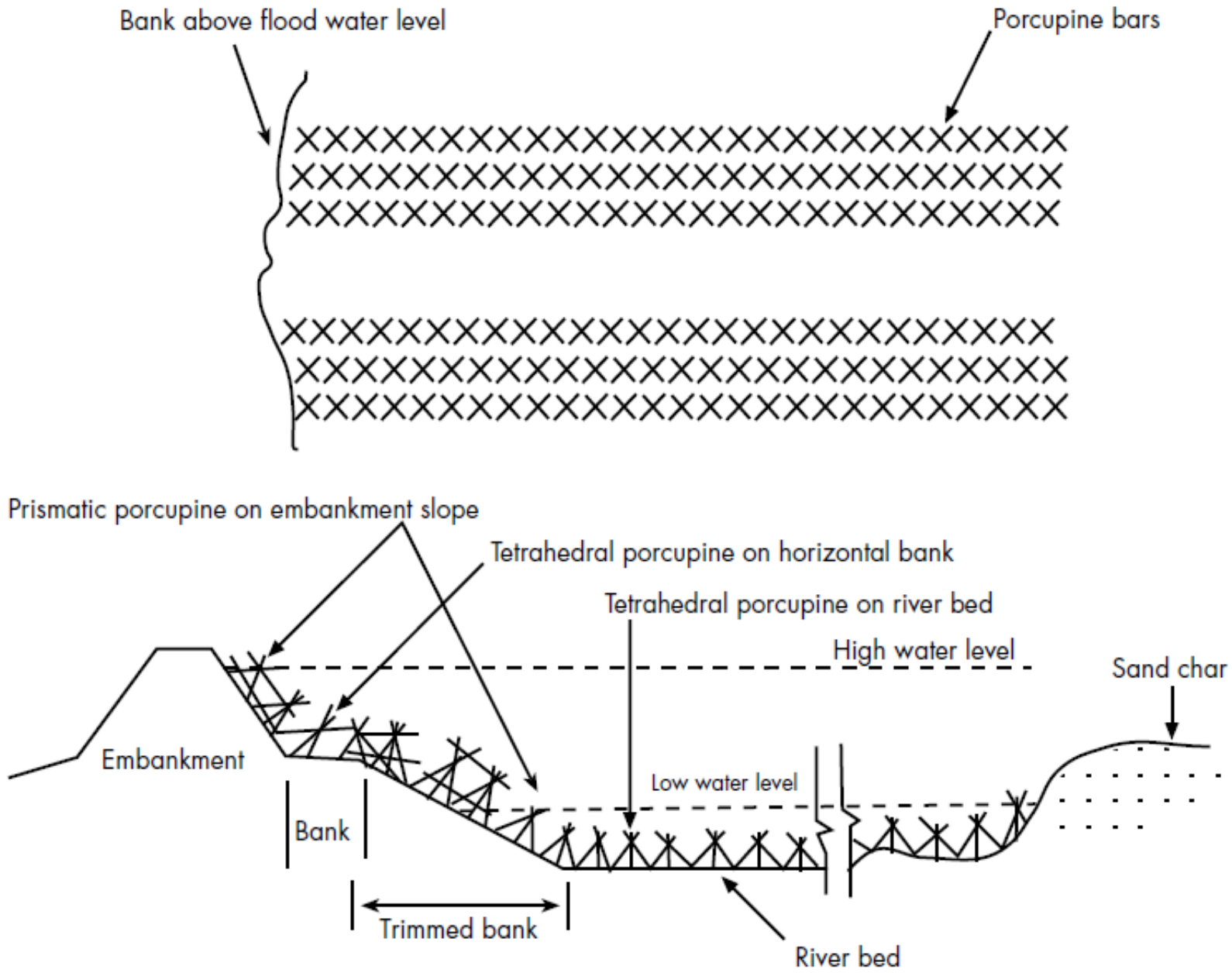


Figure 54: Plan (above) and cross-section (below) of a porcupine bar for embankment protection



River Training

Revetments and Riprap (Longitudinal Works)

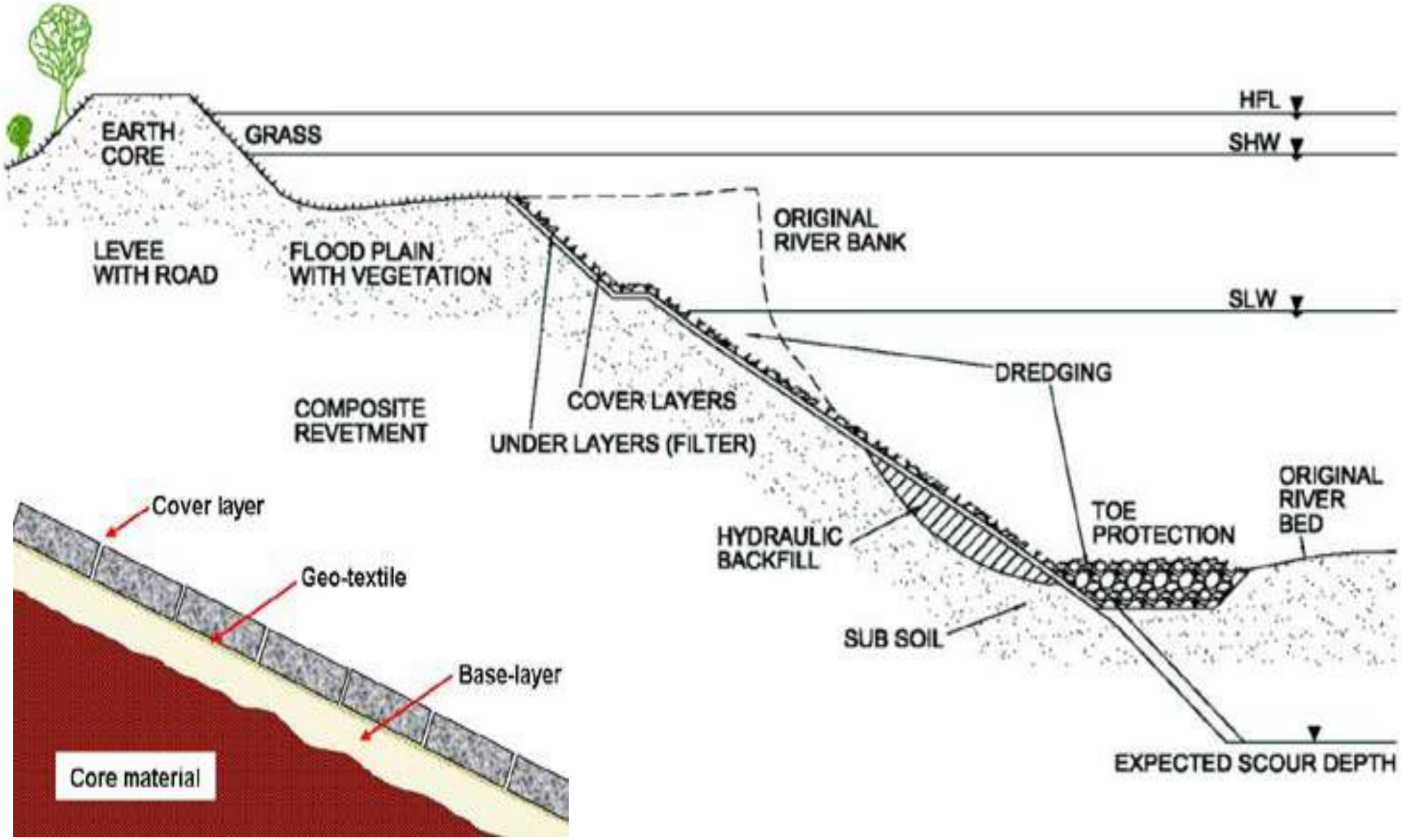
A river bank may be divided into three parts, such as:

1. Embankment portion which is called the sloping surface of the embankment facing the river.
2. Upper bank – that part of river bank which is located above the low water level and below the flood level.
3. Lower bank which portion of the river bank is in below of water surface.

Depending on the different parts of the river bank different methods of protection measures are taken.

Revetment refers to a continuous artificial surface on a river bank or embankment slope and part of the river bed which is designed to absorb the energy of the incoming water and protect against erosion by the river current. They are passive/longitudinal structures.

The function of the revetment is thus to reduce the hydraulic load acting on the soil and to facilitate stabilization of the soil. This type of river training works involve a protective cover of a suitable hard material applied on the slope and toe of the river bank so that the bank soil is protected from the actions of erosions of erosive forces of flowing water and dynamic actions of waves.



Different components of a revetment work

River Training

Revetments are of the two types:

1. Open joint type – (flexible type) in which joint gaps between individual hard materials remains open allowing free flow of water.

Open joint type revetments are suitable in situations where river water level within the bank fluctuates significantly either seasonally or diurnally because in combination with suitable filter media, such revetments are effective in releasing of hydrostatic pressure.

2. Close joint type – (rigid type) in witch joint gaps between individual hard materials are sealed using cement, bitumen, or asphaltic materials. Close joint type revetments do not allow free flow of water and are liable to develop detrimental head of water behind witch materials eventually lead to blow-offs.

Close-joint type revetments are suitable only in situations where fluctuations in water level (river or phreatic) are either insignificant or not of concern e.g. upper bank above HWL.

Revetments can be constructed from various materials including rock, stones, concrete blocks/slabs, and sandbags.

Structural Components of Revetment

A revetment normally consists of a cover layer, which provides protection against erosion forces generated by the flow, wave action and mechanical impacts from debris.

Below the cover, a filter layer is required above the underlying soil to protect the structure from seepage effects, surface runoff and down slope migration of soil particles.
Toe protection is provided at the foot of the bank to prevent undercutting caused by scour. This is done by falling apron/launching apron.

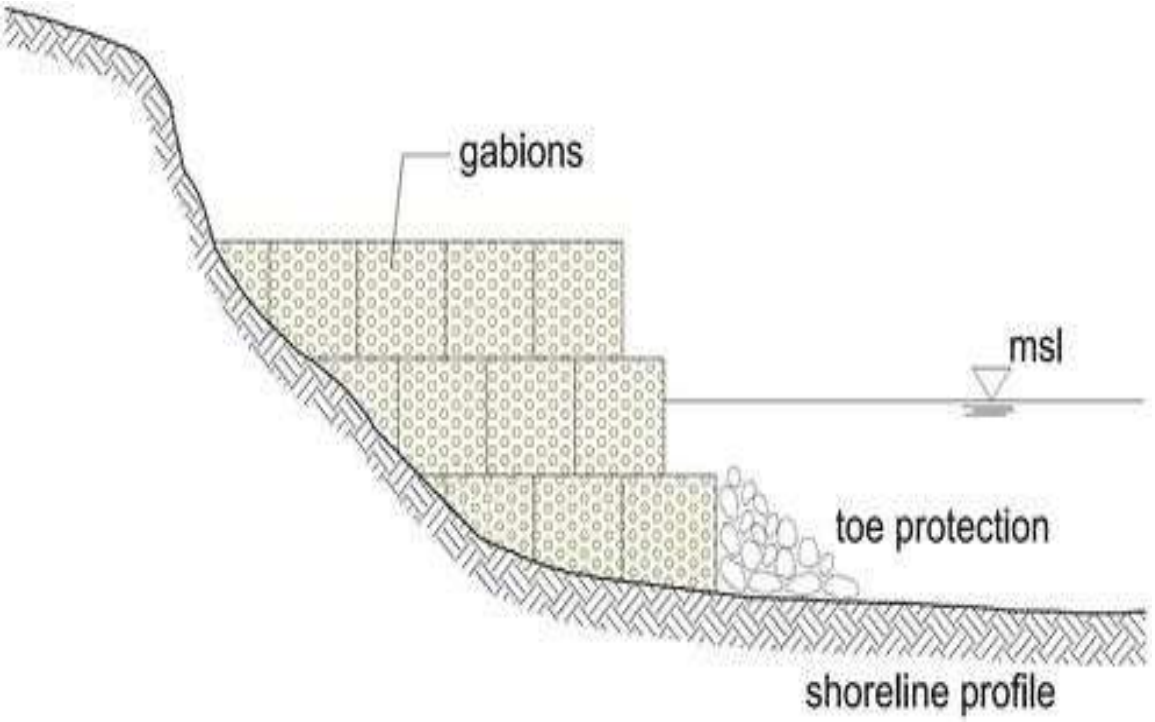
If there is a potential for scour at the toe, the revetment must be extended down to the expected level of the scour and sufficient material added in the form of a thickened toe or horizontal apron such that the toe material will launch to a stable slope as the bed scour develops.

Rock **riprap** is one of the most common types of material used to make a revetment. Riprap is a layer or facing of loose rough rock or other material used to armour embankments, streambeds, bridge abutments, pilings, and other structures subject to erosion by wave action. **Gabions** are wire box filled with small stones and can be stacked on steep slopes and provide higher resistance for the velocity range of 2-5 m/s in which small riparian stone are unstable.

Riprap absorbs and deflects the energy of floodwater and debris before it reaches the defended structure, while the gaps between the rocks trap sediment and slow the flow of water. Riprap has structural flexibility and can be constructed with locally available materials.
A riprap revetment is composed of three sections: an armour or stone layer, an underlying filter layer, and a toe protection layer.



Riprap





River Training

Armour (cover layer) is the outer layer of rough angular rock. The underlying filter layer supports the stone against settlement, allows groundwater to drain through the structure, and prevents the soil beneath from being washed through the armour by waves or groundwater seepage. The toe protection prevents downward movement of the riprap and is constructed by trenching in the riprap at the toe of the slope.

Apart from rock riprap, reformed flexible 'mattresses' can also be used to form revetments. They can be prepared from a variety of materials including soil, soil-cement, and concrete.

Bags filled with sand, soil-cement or concrete can also be used as revetment. This type of protection is used where gravel is available but large stones are rare.

Almost all the failures are due to undermining of the toe at the ends of the protection.

Difference between Riprap and Gabion

Ripraps are generally more than 30 cm in diameter – Gabions are generally 8 to 20 cm

Ripraps are placed at less slope (1:2) – As gabions are in wire mesh (caged) they can be placed at much higher slope

Ripraps are costly due size, unavailability and handling – Gabions are cheaper .

Protection Measures with Loose Concrete Blocks

Pre-cast concrete blocks generally without reinforcement are designed for a specified minimum strength with durable aggregates. Different shapes like cubical, cuboidal etc. are used. Loose blocks can be hand-placed above the low water level and dumped below low water level like rip-rap. The size of a block is generally 300 mm or 400 mm square. The concrete blocks are widely used in Bangladesh due to the fact that the blocks can be made on-site using local non-technical persons with reasonable cost.

Protection Measures with Bags (Flexible Revetment)

Jute bags, synthetic bags or geo-textile bags (called geo-bags) filled with ballast/sand can be placed in one to three layers directly on a slope or along the toe of the eroding slope or on eroding river bed. The type of ballast is to be selected considering the required flexibility and permeability of the cover layer. Sand and gravel filled bags are relatively flexible. The geo-bags filled with sand is one of the very useful material for protection of riverbank. Fine sand available in the river bed filled in geo-textile bags of desired size, can be effectively used for protection of vulnerable stretches of the riverbank.

In this approach, the slope below low water level is protected with geobags filled with sand and weigh 125 kg and 250 kg. The slope above it is protected with cement concrete blocks mainly to resist wave action.

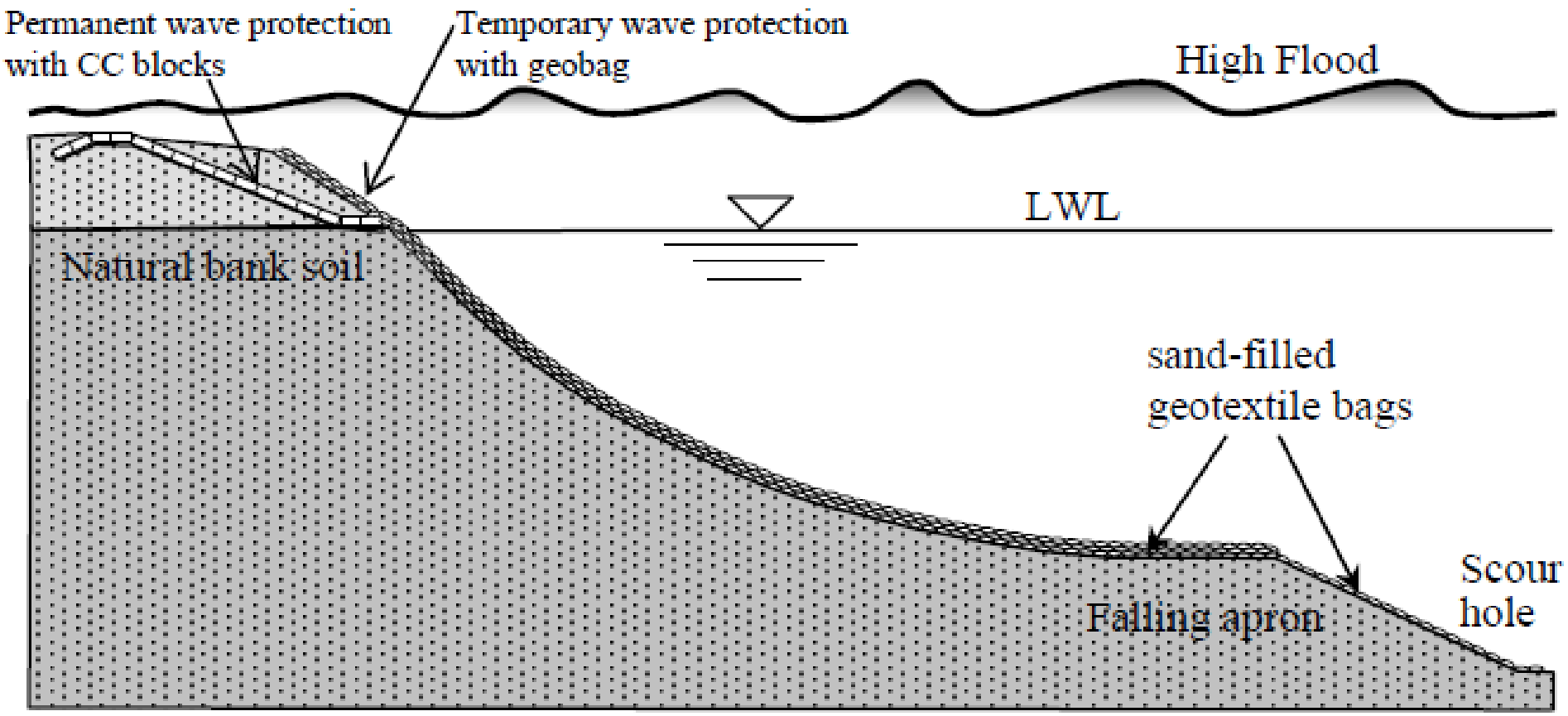
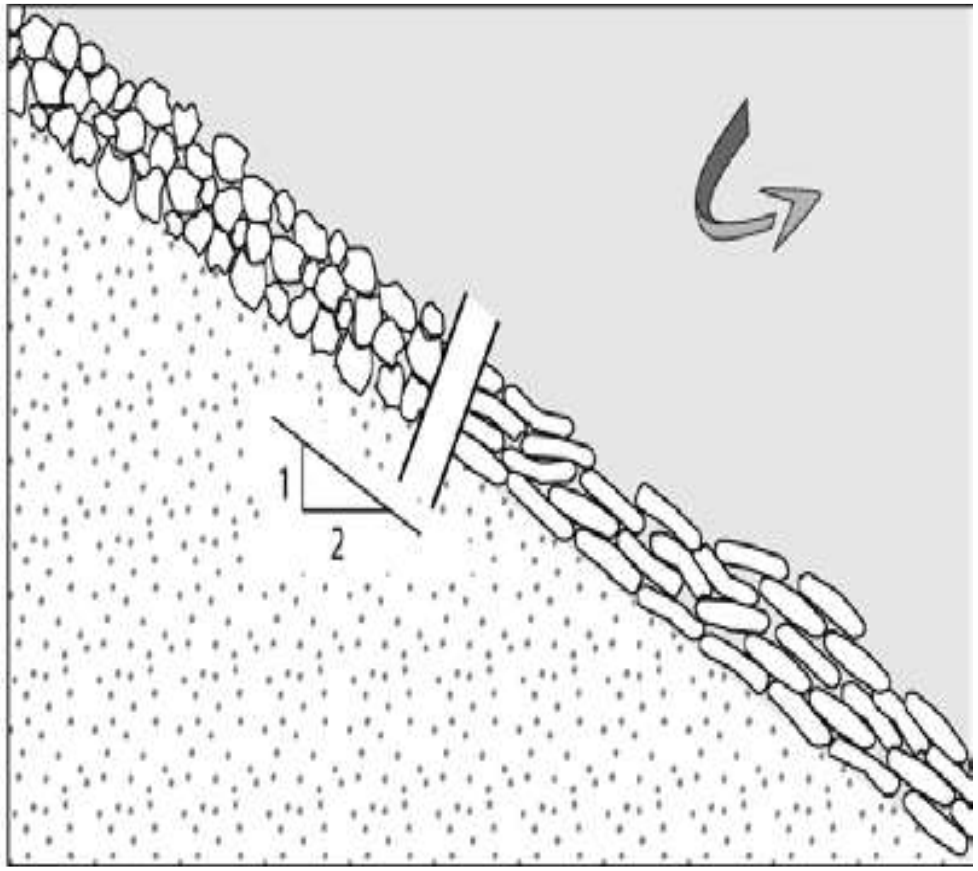


Figure 2.4 :Typical Geobag revetment (cross-section)





Different types of self adjusting revetment: multi-layer riprap and geobags (left), loose cement concrete blocks (right)







Nature-based Solutions (NBS)/Soft Approach/Bio-Engineering/Green Infrastructure

There are multiple definitions of Nature Based Solutions (NBS) but here is the one definition given by the International Union for Conservation of Nature (IUCN): NBS are defined as "*actions to protect, sustainably manage, and restore natural or modified ecosystems, which address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits*.

The terminology 'green infrastructure' (NBS) for water refers to the natural or semi-natural systems that provide water resources management options with benefits that are equivalent or similar to conventional built/physical water infrastructure. NBS use natural processes and materials to manage water flow, reduce erosion, and enhance ecological health, serving as a sustainable alternative to traditional infrastructure. They are cost effective, environment friendly and boosts biodiversity.

Research highlights that NBS could provide around 30% of the cost-effective mitigation needed by 2030 to stabilize global warming to below 2°C. They can also provide a powerful defense against the impacts and long-term hazards of climate change, which is the biggest threat to biodiversity.

Finding ways to work with ecosystems, rather than relying solely on conventional engineered solutions, can help communities adapt to climate change impacts.

Soft(er) Approaches: Bioengineering

Use of live vegetation and woody material for bank stabilization.

Often less costly in terms of materials (locally sourced), labor (often hand labor), and, once established, maintenancefree

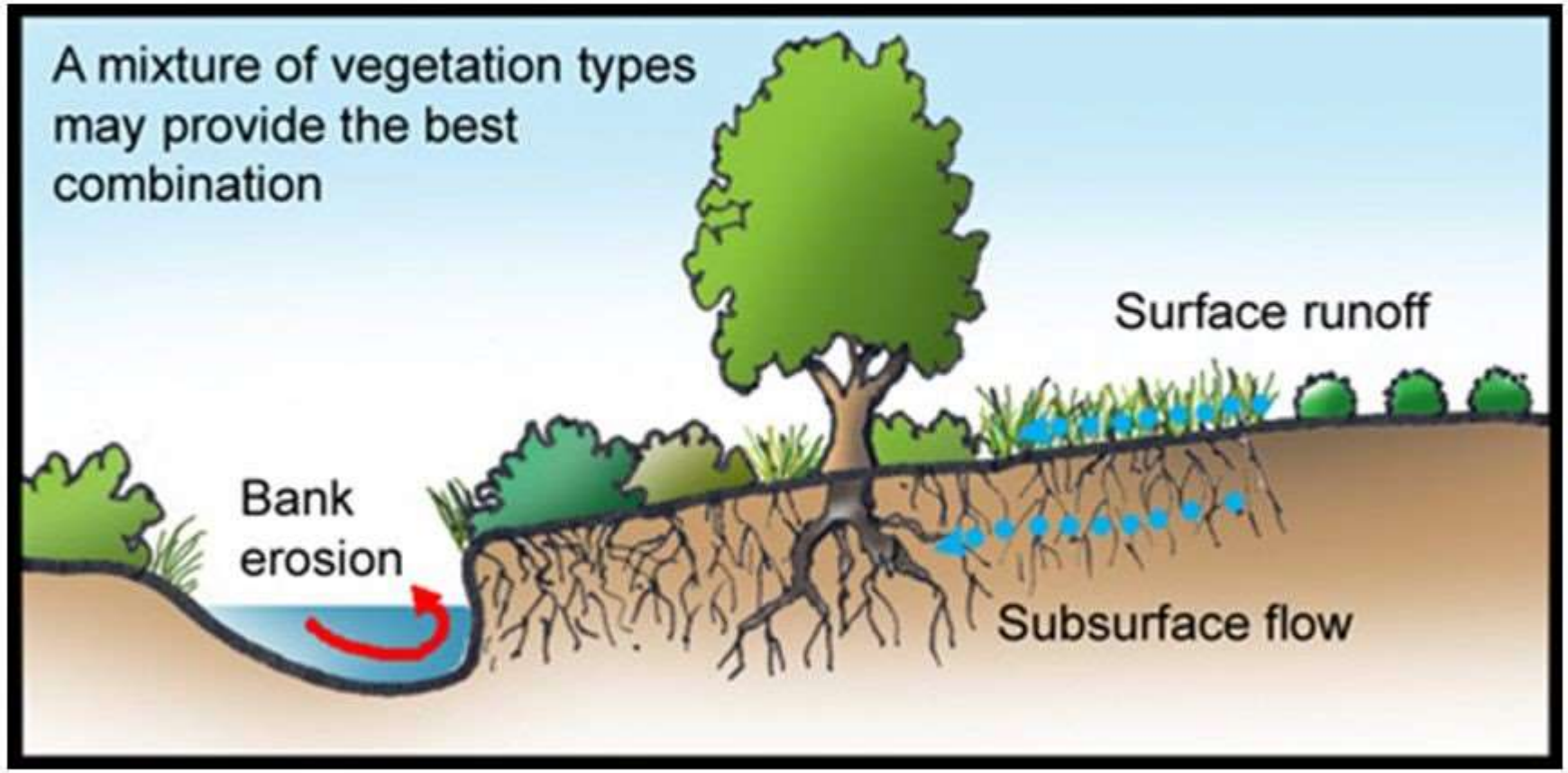
Requires time (several seasons) to establish, but self maintaining and re-generating once establish.

Mangroves (Sundari, Kewra) in coastal areas and Napier and vetiver grass in fresh water (roots going up to 4 m) are excellent for binding the soil and protecting erosion.





Plants Prevent Erosion



Roots help in holding the soil (binding), increase shear strength, reduce wave action (along with the stem) and helps in slope stabilization.



Mangrove in Coastal Zone

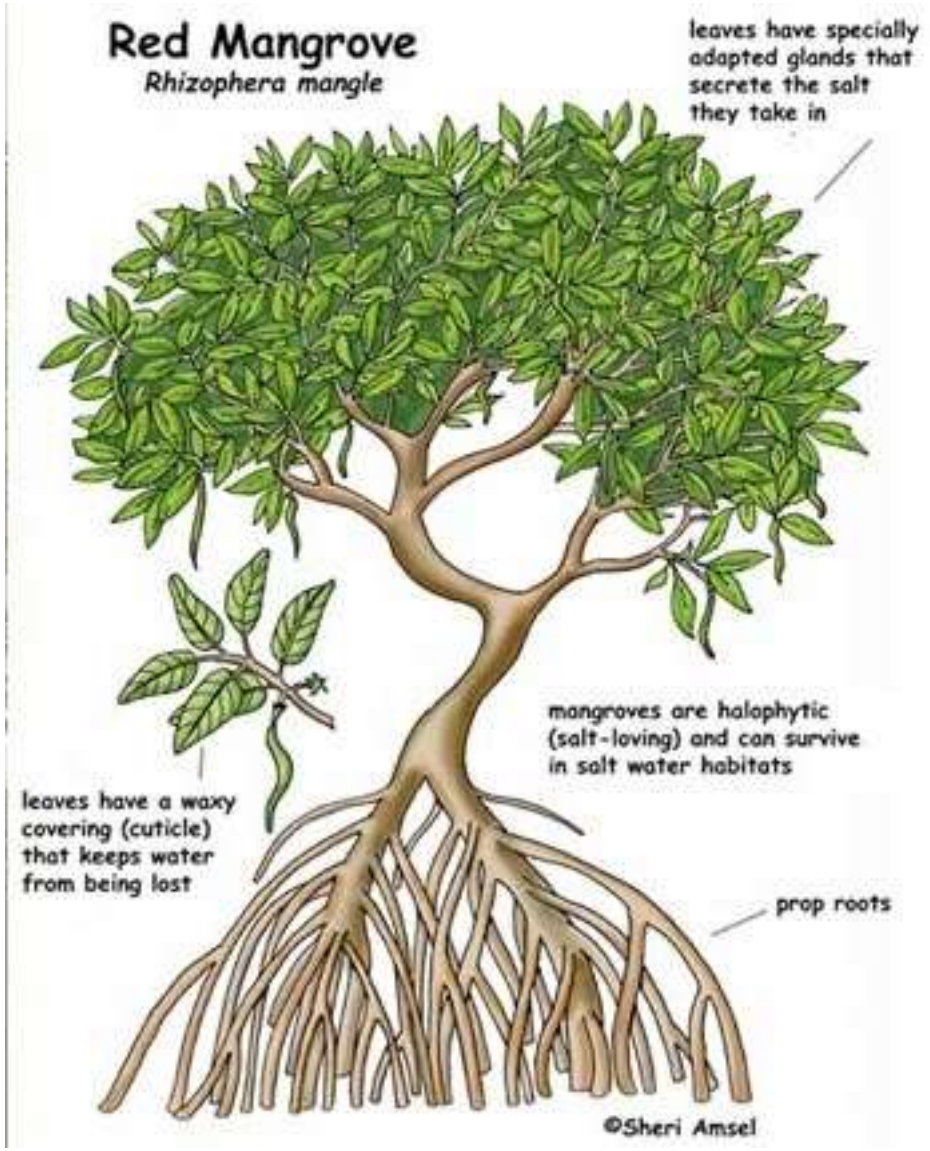


Table 5: Hard Infrastructure and Natural River Management Approaches Compared

Consideration	Hard Infrastructure	Natural River Management
Reliability	Is able to mitigate mild to extreme hazards and can be tested under a wide range of conditions	Provides less certainty and evidence of performance under full range of conditions
Flexibility	May reduce the adaptive capacity of natural systems by blocking sediment transport; adaptation to other safety levels is often costly	Harnesses and builds on the natural capacity of ecosystems to adapt to changing conditions
Timescales	Is fully functional after construction, but has limited life span	May take time to adjust and become fully functional, but can then function for decades or even centuries
Spatial Scale	Generally exerts negative effects by amplifying flood peaks on a larger scale	Reduces flood peaks on a larger scale by increasing river length and width
Social Inclusiveness	Is more likely to hamper functions that benefit the poor, such as fisheries	Is likely to have positive effects on functions that benefit the poor, such as fisheries
Planning and Implementation	Requires land acquisition in areas where construction will take place	Needs more comprehensive planning at river-basin scale; land ownership or leases should be arranged
Capital Investment and Running Costs	Requires major capital investment but lower maintenance cost	Requires less capital investment but must be closely monitored, and replenished or upgraded
Implementation	Needs a good project implementation agency	Needs a good monitoring body and long-term commitment
Ownership	Is constructed and managed by the infrastructure department	Requires collaboration between the infrastructure and natural resources and environment departments
Co-benefits	Has no clear co-benefits	Benefits fisheries, nature, recreation, and aesthetics

Source: ADB. 2019b.

Bandals for Bank Protection/Navigation

Bandals are one of the traditional river works that obstruct flow near the water surface and allow it to pass near the riverbed where major portion of the suspended sediment is concentrated. Bandals (similar to spurs or groynes) are positioned at an angle with the direction of flowing water.

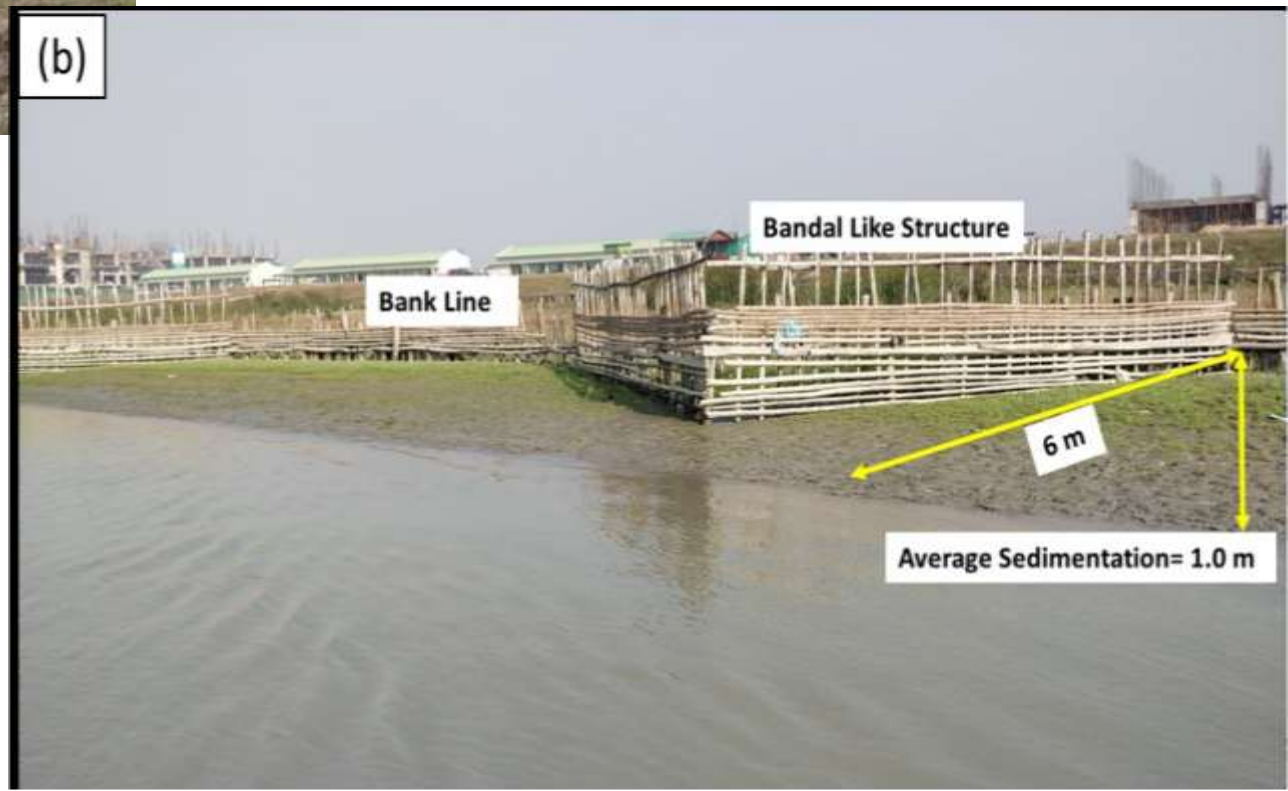
In alluvial floodplain countries, these are made of naturally available materials such as bamboos and woods and applied for the improvement of navigational channels during the dry season. Bandals are capable for protecting river banks by flow diversion towards the main channel leading to deep navigational channel formation in the main river. On the other hand, flow velocities are reduced near the bank lines that ensure bank protection by the deposition of sediment.











Lebukhali Cantonment (Payra River)

Comparing Hard and Soft Approaches

Hard, Engineering Approaches

- Advantages:
  - Durable, highly stable, can give rise to vegetation
  - Local damages can be repaired easily
- Disadvantages:
  - Need construction practice and restricted to some design parameter
  - Need manpower, materials, equipment
  - Comparatively costly

Soft, Bioengineering Approaches

- Advantages:
  - Long-term, re-generating protection
  - Often less costly
  - Potential for better environmental outcomes
- Disadvantages:
  - May require time to establish
  - Not always practical (requires, soil, water and mild slopes)
  - Can cause damage later on via wind-throw of mature vegetation