5. FLOOD PROTECTION STRUCTURES

5.1 Rivers Bank Protection

The river bank consists of the upper and lower sections. The lower bank, the part below low water, supports the upper bank and is generally more susceptible to erosion. Recession of bank is caused by the erosion of the lower bank, particularly at the toe. The recession is fast, specially when there is a sandy substratum below, the sand is washed away by a strong current and the over hanging bank collapses. The upper bank is the portion between the lower water and the high water. Action on this portion of the bank is most severe when the current attacks normal to the bank. During high stages of the flood, erosion also occurs due to a strong current along the bank.

The various types of rivers bank erosion are classified as below:

- River flow attack at the toe of the underwater slope, leading to bank failure and erosion. Usually the greatest likelihood of upper bank failure occurs during a falling river stage.
- Erosion of soil along the bank caused by current action.
- Sloughing of saturated banks with floods of long duration, due to rapid receding of flood.
- Flow slides (liquefaction) in saturated silty and sandy soil.
- Erosion of the soil by seepage out of the bank at relatively low channel flows/velocities.
- Erosion of upper bank, river bottom, or both, due to wave action caused by wind.

The river bank protection works may be classified as direct and indirect:

a) Direct protection; includes works done on the bank itself such as providing non-structural protections (see Section 7) and armoured protection (see Section 6) depending upon the severity of the current:

   - For strong current, the banks should be protected by the applicable non-structural protections such as vetiver grass, pilchi pitching, transverse killa – bushing spurs, longitudinal killa – bushing and pilchi rolls protection.
   - For very strong current, the banks should be protected by muharis (non-structural protection) or by sufficient armoured protection on the slope to

resist the tractive shear stress exerted by the flowing water. To prevent outflanking, the revetment should be provided well-entering in the bank.

b) Indirect protection; includes the works installed in front of the banks for reducing the erosive forces of current, either by deflecting the current away from the bank or by inducing silt deposition in front of the bank. The non-structural practices available are muharis, langar chhap of trees and longitudinal killa – bushing. The structural protection could be installed with different types of spurs suitable to the site conditions.

As a permanent measure a stone pitched bank, with stone apron at the toe, may be created to attract the flow and hold the river at a desired place. The positioning of the pitched bank will be determined with due consideration of travelling of river meandering downstream and it must be checked by a controlling spur. The stone pitching gives the bank a certain rigidity which induces scour at its toe. Because of the scour, the main river channel tends to be drawn on to the pitched bank itself and held there permanently. Thus the pitched bank becomes a control point in the river.

5.2 River Containing Structures

5.2.1 General

The directing of flows in a defined stretch of the river is usually required to protect hydraulic structures like barrages, weirs, bridges etc. in danger of oblique attack or outflanking. The normally used river containing structures are flood bunds, retired bunds and marginal bunds. These structures also, facilitate the containing of river spill and provide protection from flooding to the flood prone/areas.

5.2.2 Flood Bunds

Flood bunds are low height earthen embankments extending, generally, parallel to the river channel and designed to protect the area behind it from overflow of floods.

Generally, flood bunds are aligned on the high ridge of the natural banks of a river, where land is high and materials available in the vicinity are suitable for the construction of embankment. The alignment is kept reasonably straight by avoiding acute curves and intrusion into the river khadir (i.e. the historical movement limits or distance between the two high banks of the river). The flood bunds are also so aligned that inhabited areas, settlements and properties along the river bank are left outside the bund. Sometimes, a ring bund has to be provided to protect these areas from inundation, if they happen to fall within the river khadir.

Typical cross-sections of flood bund and flood bund with wetting channel (or soaking trench) are given in Figure 5.1. In locations, where bund mostly remains dry it may be necessary to provide a wetting channel on the riverside. The basic design criteria for the earthfill embankment is:

- Crest width = 25 ft (7.5 m)
- River side slope = 3H:1V
- Landside slope = 2H:1V
- The cross section of the embankment will be designed to satisfy the hydraulic gradient of 6:1 (for common material) at the design flood level (or HFL) .The hydraulic gradient (6:1) should exit minimum two (2) feet (0.6 m) below NSL at landside toe of the embankment. Where this is not practicable, a horizontal gravel drainage blanket may be provided on the landside toe to ensure the stability of slope and prevent its failure through piping.
- A six (6) inch (150 mm) thick compacted gravel and sand surfacing will be placed on the crest for protection against flood water spray, rain runoff and traffic wear and tear.

During high stages of the flood erosion of the embankment may occur locally due to a strong current along the bund. In such cases indirect protection works will be installed in front of the bund for reducing the erosive forces of current. These works may include different types of non-structural or structural protections to suit the site requirements. In places direct protection of the embankment may be required. This will consist of stone pitching on the riverside slope of the embankment starting with a stone toe. Top level of the stone toe will be at par with the low water level (LWL) of the river. For dry conditions the toe will consist of suitable size gabions (or stone crates) with its top level at the river bed level.

Where the bund will be founded on a permeable foundation the foundation will be treated by providing a sand filled trench or cutoff of material to suit site conditions, running longitudinal along the bund. Such treatment will prevent the developing of flow line along the base of the bund.

5.2.3 Retired Bunds

The retired bunds are built at a distance from the river edge behind the existing flood bund as a second line of defence or replacing damaged flood bunds. The typical design criteria for retired bunds are the same as described above for the flood bunds.

5.2.4 *Marginal Bunds*

The marginal bund (or afflux embankment) is provided to contain river spill generated by raising of water level at a barrage, bridge, syphon etc. Due to backwater effect, at locations, the marginal bund could extend up to twenty (20) miles (32 km) length.

Generally, marginal bunds are aligned by following the river banks if they are not far off. In case the banks are far off, the bunds are aligned in alluvial river bed, but away from the high velocity flows. The marginal bunds are normally anchored to the guide banks or start from about five hundred (500) feet (150 m) upstream of the gate-line of the barrage. They are tied with high land or existing flood bund where no more spill over is anticipated.

Since the rivers change their course, it is not necessary that a particular alignment of the marginal bund that is safe for a particular flow condition will remain safe with the passage of time when river conditions have changed. When such contingencies develop, proper river training works will be introduced.

In reaches, where current attack or wave-wash are anticipated the riverside slope of the bund will be protected with stone pitching, underlain with graded spall and filter layers, and starting with a stone toe.Top level of the stone toe will be at par with the low water level (LWL) of the river. For dry conditions the toe will consist of suitable size gabions (or stone crates) with its top level at the river bed level. At later stage the stone toe could be converted to stone apron if high flow velocity and river bed scouring is anticipated along the embankment.

Typical cross-sections of normal earthen marginal bund and bund with slope protection are given in Figure 5.2. The basic design criteria for the embankment are:

- Crest width = 25 ft. (7.5 m)
- Riverside slope, earthen = 3H:1V
- Riverside slope, protected = 2H:1V
- Landside slope = 2H:1V
- The cross-section of the embankment will be designed to satisfy the hydraulic gradient of 6:1 (for common material) at the design flood level (or HFL). The hydraulic gradient (6:1) should exit a minimum two (2) feet (0.6 m) below NSL at landside toe of the embankment. Where this is not practicable, a horizontal gravel drainage blanket may be provided on the landside toe to ensure the stability of slope and prevent its failure through piping.

- A six (6) inch (150 mm) thick compacted gravel and sand surfacing will be placed on the crest for protection against flood water spray, rain runoff and traffic wear and tear.

5.3 River Training Structures

5.3.1 General

River training covers various type of structures constructed on a river to guide and confine the flow to the river channel. Also, to control and regulate the river bed configuration for effective and safe movement of floods and river sediment. River training aims at controlling and stabilizing a river along a desired course with a suitable waterway, for one or more of the following purposes:

- Flood protection; to provide sufficient cross-sectional area for the safe passage of the maximum flood. It concerns, essentially, proper location, alignment and height of embankment for a given flood discharge, without an attempt at changing the river bed conditions.

- Bank protection; to deflect the flow away from the bank to prevent bank erosion. Generally, there is a tendency of meanders either to shift downstream or form cutoffs. The process of bank erosion is therefore, constantly active and river training for the protection of banks continues to be a recurring problem.

- Sediment control; to rectify river bed configuration and efficient movement of suspended and bed load for keeping the channel in good shape.

- Land reclamation; to reclaim land for cultivation from wide river sections in the plains.

- Confined river channel; to rectify the alignment of the river where abnormal changes have taken place e.g. splitting of river section into various branches, development of sharp bends or meandering and formation of wide and shallow shoals.

The design of large subprojects/schemes, which will be implemented over a number of construction seasons, will be based on "real time" data. Continuous changes in river behaviour may require major revisions to the original design to suit prevailing conditions in subsequent seasons.

All training works will be environmental –friendly. The acceptability of each design shall be confirmed and improved through physical model studies.

5.3.2 Spurs (or Groynes)

The spurs (or groynes) are structures placed transverse to the river flow and extend from the bank into the river. These are widely used for the purpose of river training and serve one or more of the following functions:

- Training the river along a desired course by attracting, deflecting (or repelling) and holding the flow in a channel. Spurs are classified as:
  - Attracting spur; if it creates deep scour near the bank.
  - Deflecting (or repelling) spur; if it shifts deep scour away from the bank.
  - Holding spur; if the deep scour is held at the head of the spur.

- Creating a zone of slack flow with the object of silting up the area in the vicinity of the spur.

- Protecting the river bank by keeping the flow away from it.

To serve the desired purpose, the requirements of a spur are;

- Optimum alignment and angle consistent with the objective.

- Availability of high river bank to anchor (or tie) the spur by extending it landward into the bank line for a sufficient distance to avoid any outflanking during high flood. The anchoring distance may vary from a minimum of fifteen (15) feet (4.5 m) to fifty (50) feet (15 m)or more depending upon the major channel changes.

- Crest level (or freeboard provision) sufficiently above HFL in case of non-submerged spurs.

- Fairly stable flow entry condition at the upstream.

- Adequate protection to nose/head against anticipated scour.

- Shank protection with stone pitching and stone apron for the length which is liable to flow attack on the upstream side of the shank.

Depending upon the purpose, spurs can be used singly or in series. They can also be used in combination with other training measures. Their use in series is introduced if the river reach to be protected is long, or if a single spur is not efficient/strong enough to deflect the current and also not quite effective for sediment deposition upstream and downstream of itself. The structure located the farthest upstream in a series of spurs is much more susceptible to flow attack both on the riverward and landward ends. Thus it should be given special treatment to ensure its structural stability.

The position, length and shape of spurs for the individual subproject/scheme will be determined by physical model studies. The choice of spur types will be based on efficiency, site suitability and desired purpose. No single type of spur should be generalized in all locations.

a) *Alignment of Spurs*

Spurs may be aligned either perpendicular to the bank line or at an angle pointing upstream or downstream, as shown in Figure 5.3. The figure also illustrates the action of spur/river related to the spur alignment and as classified below:

i. *Repelling Spur*

A spur angled upstream repels the river flow away from itself and is called a repelling spur. The repelling spurs are preferred where major channel changes are required. A spur originally angled upstream may eventually end up nearly perpendicular to the streamlines after the river course changes by development of an upstream side silt pocket and scour hole at the head.

Repelling spurs are generally aligned from 10 to 30 degrees with a line perpendicular to the bank. Generally, the head of a repelling spur causes disturbance at its nose and heavy scour occurs. These spurs should therefore, have strong head to resist the direct attack of a swirling current. A silt pocket is formed on the upstream side of the spur, but only when the spurs are sufficiently long. Repelling spurs are usually constructed in a group to throw off the current away from the caving bank. A single spur is neither strong enough to deflect the current nor effective in creating silt deposition upstream and downstream.

ii. *Attracting Spurs*

A spur angled downstream attracts the river flow towards itself and is called an attracting spur. The angle of deflection downstream ranges between 10 to 30 degrees from a line perpendicular to the bank. The attracting spur bears the full energy of the frontal attack of the river on its upstream face, where it has to be armoured adequately. Heavy protection is not necessary on the downstream slope. It merges into the general stream alignment more easily. The scour hole develops off the riverward end of the structure

iii. *Deflecting Spur*

When an upstream angled spur of short length, changes only the direction of flow without repelling it, it is called a deflecting spur. Deflecting spur gives only local protection.

iv. *General*

The angle which a spur makes with the current may affect its performance (Ref: 5.1). A spur built normal to the stream usually is the shortest possible and thus economical. An upstream angle is better to protect the riverward end of the spur against the anticipated scour. A downstream angle might be better for protecting a concave bank, especially if spacing and the lengths of the spurs are such as to provide a continuous protection by deflecting the main currents away from the entire portion of bank.

b) *Spacing of Multiple Spurs*

The spacing between spurs generally depends on the length projected by each spur in the series. The general recommendations on spacing are (Ref:5.2):

- The spurs are spaced further apart, with respect to their lengths in a wide river than in a narrow river, having nearly equal discharge. The normal spacing in straight reach will be five (5) times the length of spur.

- The location of spurs affects their spacing. A larger spacing may be adopted for convex banks and a smaller spacing for concave banks. In general, the recommended spacing is:

    - Convex bends; 2 to 2.5 times the length of spur

    - Concave bends; equal to the length of spur

- When the river bank has a curvature, the spurs in series may have varying lengths and, therefore, varying spacing. The angle of deflection of spurs may also change continuously according to the curvature of the bank line.

c) *Length of Spurs*

No general rules can be formulated for fixing the length of spurs. It depends entirely on the conditions and requirement for the each specific site. The length should not be shorter than that required to keep the scour hole formed at the nose away from the bank. Short length may also, cause bank erosion upstream and downstream of the spur due to eddies formed at the nose. A long spur may dam up the river and would not withstand the flood attack from discharge concentration at the nose and a high head across the spur. Normally spurs longer than one fifth (1/5) the river width are not provided.

The length of spurs a well as their orientation, shape etc., can best be finalized from physical model studies.

d) *Types of Spurs*

Normally, spurs comprise an earthen embankment with a horizontal crest. The shanks are typically unprotected. The shank, on its riverward end, is provided with an impregnable protected/armoured head for training a river. The different types of spurs commonly used, named according to the shape of their impregnable heads, are shown in Figure 5.4, and listed below:

- Bar spur
- Mole-head spur
- Hockey spur
- Inverted hockey spur
- T-head spur

- Sloping spur
- T cum hockey-sloping spur
- J – head spur
- Guide-head spur

Typical cross-sections of the unprotected shank and protected head are given in Figure 5.5. The basic design criteria for the embankment is:

- Crest width = 30 ft (9 m)
- Side slopes – Shank = 3H:1V
  – Head = 2H:1V
- A six (6) inch (150 mm) thick compacted gravel and sand surfacing will be placed on the crest of shank and head for protection against flood water spray, rain runoff and traffic wear and tear.

A brief description of each type of spurs is given in the following paragraphs:

e) *Bar Spur*

The bar spur (Figures: 5.4 and 5.5) is the simplest type of spur. It is a straight embankment with armoured head and projects into the stream transverse to the flow.

f) *Mole Head Spur*

A bar spur with armoured rounded head of increased width is known as mole head spur (Figure: 5.4 and 5.5).

g) *Hockey Spur*

The hockey spur (Figures: 5.4 and 5.5) follows the shape of a hockey stick with stone protection on the concave face and head and for a short length on the convex face. Some typical behaviour characteristics of hockey spur observed by physical model studies (Ref: 5.3) are reproduced below:

i. A hockey spur can be installed successfully for checking a deeper embayment. The angle of deflection of the main current downstream of the spur increases with the increase in depth of embayment upstream of the spur.

ii. The flow concentrates at the nose of the spur which sets up an intense eddy at the back of the spur nose and a significant secondary current is directed towards the shank.

iii. A follow-up spur at an optimum position downstream of the hockey spur is essential to form a pocket that will reduce the eddy and keep off the secondary current.

h) *Inverted Hockey Spur*

The inverted hockey spur (Figures: 5.4 and 5.5) is the mirror image of hockey spur. It is provided with stone protection on the convex face and head and for a short length on the concave face. Some typical behaviour characteristics of inverted hockey spur observed by the physical model studies (Ref: 5.3) are reproduced below:

i. The deflection of the main current imposed by the inverted hockey spur is much less than the hockey spur. The flow moves backward to the spur shank after moving for some distance downstream of the spur.

ii. Inverted hockey spur acts as an attracting spur if placed in series on a river bank.

iii. Secondary current is not generated at the back of an inverted hockey spur.

i) *T-Head Spur*

The T-head spur (Figures: 5.4 and 5.5) follows the shape of English letter "T". The head is generally placed parallel to the flow with about two third (2/3) length on the upstream side of the shank and one third (1/3) on the downstream side. Some typical behaviour characteristics of T-head spur observed by the physical model studies (Ref: 5.3) are reproduced below:

i. Performance of the T-head spur when river channel approaches tangentially to the spur head and forms a mild embayment upstream of the spur head is reasonably acceptable. The main current gets deflected, the angle of deflection depending upon the magnitude of embayment forming upstream of the spur head. The stone apron launches gradually and uniformly with the rising flow and covers the subaqueous slope below the apron down to the deepest scour level.

ii. An eddy forms along the nose of spur head, moving up and down the armoured slope. A proper filter under the stone pitching will be essential.

iii. With the formation of deep embayment upstream of spur head the main current gradually drifts towards the shank and ultimately starts attacking it. The shank may break at the point of attack.

iv. The high concentration and spiral eddies forming at the upstream nose of the spur head do not allow smooth launching of the stone apron. Stones from the apron are picked up by the high velocity spiral currents and swept away, ultimately causing the collapsing of the spur head.

v. If the length of head upstream of junction point is inadequate and scour hole from the nose extends up to the junction point, the shank will fail at the junction point.

vi. When the river channel approaches head-on to the spur head it creates heaving and surging in the pocket upstream of the spur head. This rise and fall in water level upstream of the spur head is not safe for the shank.

j) Sloping Spur

The sloping spur (Figures: 5.4 and 5.6) is a wedge shaped ramp of solid stone, with its height decreasing from bank to riverward at a slope ranging from 6H:1V to 10H:1V. Sloping spur is, generally, installed for the training of hilly streams. Some typical behaviour characteristics of sloping spur observed by the physical model studies (Ref: 5.3) are reproduced below:

i. No secondary current gets generated at upstream of the spur.

ii. There is less resistance to stream flow, resulting in lesser head across the spur.

iii. With increase in stream discharge a greater length of spur comes into action. Thus the extent of the eddy reduces and the main current gets deflected away from the stream bank.

iv. The point of maximum scour is away from the spur nose.

v. The optimum top slope for most effective performance of the spur is 10H:1V, normally adopted for larger rivers.

vi. The optimum angle of spur axis with respect to flow axis is ninety (90) degrees.

vii. The spur is most effective for straight river approach. Its effectiveness reduces with the obliquity in river approach.

viii. The spur will hold the stream near its nose and will thus reclaim the land on its upstream.

k) T cum Hockey-Sloping Spur (or J-head spur)

The T cum hockey-sloping spur (or J-head spur) is a combination of T-spur, hockey spur and sloping spur (Figures: 5.4 and 5.5). The spur design elements are:

i. Hockey-part ; optimum radius of the spur shank at its junction with the spur head.

ii. T-part; alignment and length of the spur head.

iii. Sloping-part; optimum slopes for the upstream and downstream ends of the spur head.

iv. Stone-apron; effective dimensions and stone size on the performance of the spur head and upstream face of shank.

Some typical behaviour characteristics of J-head spur observed by the physical model studies (Ref: 5.3) are reproduced below:

i. With the increase in radius of hockey-part the embayment upstream of spur head increases and the entire flow converges at the upstream end of the spur head and after leaving spur nose it swings towards the opposite bank. The silt carrying bottom current move towards the concave bank, forming a sand bar downstream of the spur.

ii. There is no definite relationship for fixing the length of the spur head. On the basis of past experience the recommended length (but not limited to) of spur heads for the main rivers are:

- Sutlej and Ravi = 300 – 400 ft (90 – 120 m)
- Jhelum = 400 – 600 ft (120 – 180 m)
- Chenab = 500 – 750 ft (150 – 230 m)
- Indus = 600 – 1000 ft (180 – 300 m)

iii. With shorter radius of spur head the eddy forming at the upstream end of the spur reduces in extent and the flow follows the head for most of its length. As the downstream end of the head bends towards the bank most of the flow is directed to it in the form of a secondary channel. In case of longer radius the tail end of the spur extends almost straight. Only a small flow is directed in the secondary channel. With the increase in the radius of spur head the eddy forming along the upstream nose increases in extent and in intensity, thus there is increase in the scouring.

iv. When there is head-on attack of the flow at the tail end of the spur, the spur acts as a sloping spur. After impingement, the main current receives a deflection towards the opposite bank and an eddy forms along the downstream face of the shank. With flattening/lengthening of the tail end slope of the spur head the scour hole shifts lower down from the tail end of the spur.

v. When the spur head is placed parallel to the main current the flow approach is tangential to the spur head and runs almost parallel to it. With the development of scour hole at the spur head nose, embayment starts forming upstream of the spur head and deepens with time and rise in river flow. At this stage the main current is slightly deflected towards opposite bank and an eddy develops along the upstream end of the spur head. With the deepening of the embayment, the flow concentration and intensity of eddy increases and becomes dangerous to the spur head. However, with the increase in angle of orientation of spur head, the flow concentration at the spur head nose and the eddy along upstream portion of the spur head reduce generally till the eddy is eliminated completely. But at the same time an eddy develops at the back of the spur which gains acceleration with the increase in the angle of orientation and poses a threat to downstream face of the unprotected shank. The maximum angle of orientation recommended is ten (10) degrees.

l) *Guide-Head Spur*

The guide-head spur is a combination of T-spur, hockey spur and sloping spur (Figures: 5.7 and 5.5). The spur design elements are:

i. Hockey-part; optimum radius of the spur head at upstream end.

ii. T-part; alignment and length of the spur head.

iii. Sloping-part; optimum slope for the downstream end of the spur head.

iv. Stone-apron; effective dimensions and stone size on the performance of the spur head and upstream face of the shank.

The typical behaviour characteristics of guide-head spur could be taken similar so the J-head spur, discussed above.

m) *Spur Head With Cast-in-place Concrete Piles*

A typical mole head spur with cast-in-place concrete piles is shown in Figure 5.8. In this type of spur, the piles constitute the main verticals, placed down to the anticipated scour depth plus embedded length in the river bed. The pile top is maintained at the crest level of the spur head. Piles are spaced three (3) foot (1.0 m) centre to centre. This arrangement can be used for any spur type depending upon the site suitability.

Stone filling is provided between the pile verticals. When channel bed scouring occurs along the line of piles some small stones will fall through the vertical gaps into the scour holes. This loss will depress the stone filling between the pile verticals. Replenishment of stone continues during the period of channel bed scouring.

The basic design criteria for the cast-in-place concrete piles is:

- Pile diameter = 22 in. (560 mm)
- Point of fixity will be at the anticipated maximum scour level.
- Concrete type = RCC, 3000 psi (1:2:4) (211 kg/cm^2)
- Reinforcement = Grade 40, deformed bars. Minimum longitudinal bars are provided at one percent (1.0 %) of the concrete area.
- Concrete cover = 3 in. (75 mm)
- Design forces = self weight, hydrodynamic force and active pressure from stone filling.
- Embeded length = to sustain self weight and moments from design forces

n) *Choice of Type of Spur*

Various factors which influence the choice and design of spurs are as below:

i. Gradient and velocity of river.

ii. Available construction materials.

iii. Type of bed material carried by the river (i.e. shingle, sand or silt).

iv. Quantity of silt load in river flow.

v. River width or waterway available at high, medium or low discharge.

vi. Depth of waterway and flood hydrograph.

Permeable spurs are best suited to erodible bed rivers normally carrying heavy-silt-laden flow. These are not suitable for small rivers, having steep gradients or deep rivers carrying light-sediment load.

Impermeable spurs are most suitable for confining a river to defined channel.

Spurs may be aligned perpendicular or inclined to the bank line, pointing upstream or downstream. The fixing of angle of spur with respect to current axis will require physical model study.

5.3.3 *Studs*

Studs are short bar-spurs used as protection against spill flow causing erosion along a river bank or flood embankment. These are placed in series at suitable locations in the spill flow channel along the bank. They reduce erosion by deflecting the high velocity currents away from the eroding bank. For anchoring of studs they are well extended into the bank, having similar section as placed riverward.

The studs are repaired and additional studs are constructed from time to time depending upon the conditions of the river during and after the flood. The series of studs are often used in lieu of direct bank protection, because they are more economical and do not disturb the near-bank environment.

Depending upon the flow velocity, the following four types of studs are used:

i. Earthen stud; in spill flow channel with low velocity.

ii. Earthen stud with stone protection; in spill flow channel with high velocity.

iii. Earthen stud with stone protection and armoured leading nose; in spill flow channel with high velocity and leading nose under current attack of main channel.

iv. Solid stone stud; when main channel current attacks the bank.

The typical cross-sections for different types of studs are given in Figure 5.9. The basic design criteria for the embankment is:

• Crest width	-	Earthen stud	= 12 ft	(3.5 m)
	-	Earthen stud with stone protection	= 12 ft	(3.5 m)
	-	Solid stone stud	= 8 ft	(2.5 m)
• Side slopes	-	Earthen stud	= 3H:1V	
	-	Earthen stud with stone protection	= 2H:1V	
	-	Solid stone stud	= 2H:1V	

5.3.4 *Guide banks*

A river generally flows in a wide khadir (i.e. the historical movement limits or distance between the two high banks of the river) and it is necessary to narrow down and restrict its course to flow centrally through the barrage, weir or bridge placed across it. Guide banks are placed in pairs symmetrical in plan. It is essential that the design should be such that no swirls are produced and alignment is smooth. There should be no spurs projecting from the guide bank as the spurs produce swirls.

a) Forms of Guide Banks

Guide banks can be divergent or convergent in form upstream of the structure, as shown in Figure 5.10 and discussed below:

i. Divergent guide banks require a longer length and also provide less protection under possible embayment. They induce oblique flow on the structure and cause shoal formation in the center due to larger waterway between curved heads. However, in cases where approaching flow is oblique, it is essential to provide divergent guide banks to keep the flow active in all the spans of the structure.

ii. Convergent guide banks have the disadvantages of excessive flow attack and large scouring at the head and create shoals along the banks rendering the end bays of the structure inactive.

iii. In special situations, other forms of guide banks may be provided, if their suitability is confirmed by physical model studies.

b) *Length of Guide Banks*

The length of guide banks is decided in consideration of the following factors:

- The distance necessary to secure a straight and normal flow approach to the structure so as to minimize the obliquity of current.
- To safely protect the approach banks on both sides of the structure from river embaying behind the training works.
- To ensure that the swirls and turbulence, likely to be created by the spreading out of flow downstream of the guide banks, do not endanger the structure.
- The length necessary to prevent the edge of bend or meandering of the river at upstream and behind the guide bank.

The typical plan of the guide bank (Bell's Bund) showing its length is reproduced (Ref: 5.4) in Figure 5.11.

c) *Radius of Bank Head*

The proper radius of upstream bank head depends on the velocity of the river. Spring gives the following table to design the radii, related with the probable maximum scour and river gradient (Ref: 5.4):

Sand Classification	**Probable Maximum Scour (ft)**	**River Gradient (inches per mile)**				
		3	**6**	**9**	**12**	**18**
		Radius of Upstream Bank Head (ft)				
Very Coarse	< 20	200	250	300	350	400
	> 20	250	310	375	440	500
Coarse	< 30	300	360	425	490	550
	> 30	350	430	510	590	670
Medium	< 40	400	425	550	625	700
	> 40	450	550	650	750	850
Fine	< 50	500	590	675	760	850
	> 50	600	725	825	925	1020
Very Fine	< 60	600	700	800	900	1000
	> 60	800	900	1000	1100	1020

The upstream bank head curve should be carried 120 to 140 degrees round the back to protect the landside of the bank.

d) *Typical Sections of guide Banks*

The typical sections of the guide banks are given in Figure 5.12. The basic design criteria for the embankment is:

- Crest width = 30 ft (9 m)
- Protected side slope = 2H:1V
- Unprotected side slopes = 3H:1V
- A six (6) inch (150 mm) thick compacted gravel and sand surfacing will be placed on the crest of guide bank for protection against flood water spray, rain runoff and traffic wear and tear.
- The embankment will be protected with stone pitching, underlain with graded spall and filter layers, and flexible stone apron on the riverside slope, upstream head and downstream end.
- The final geometry of the guide banks will be determined by physical model studies to suit the site requirements.

5.3.5 Pitched Islands

The pitched island is used as a river training measure for its ability to cause re-distribution of velocity and tractive force. The tractive force near a pitched island begins to increase rapidly, with the result that deep scour begins to form round the island and gradually draws the main river channel towards it and holds it permanently. Pitched islands are used either singly or in series, for the following purposes:

- Correcting oblique approach upstream of weirs, barrages and bridges by training the river to be axial.
- Altering the river flow pattern and stabilizing its course.
- Redistributing harmful concentration of flow for relieving attack on guide banks, marginal bunds and river bends.

Sometimes, advantage may be taken of an existing natural island (a bela) which can be reshaped and pitched accordingly.

Scour at the toe of a steeper slope is deeper than at the toe of a flatter slope. Different side slopes are given to the pitched island when it is used for redistribution of concentration of flow. A steeper slope (usually 2H:1V) is adopted on the side on which a concentration of flow is desired, while a flatter slope is given on the side where a deflection is required.

In the case of wide and shallow rivers, where obstruction caused by the island would be very small, scour will not develop round the island readily. Similarly in flashy rivers, there is not enough time for the development of scour round the island. In such cases, the pitched island may not be successful in achieving the desired results.

The pitched island is usually shaped as elliptical or egg-shaped, as shown in Figure 5.13. The upstream nose is round and broad, while the downstream end is provided with a narrow tail. Generally, its body consists of compacted river bed material, protected with stone pitching, underlain with graded spall and filter layers, on the side slopes and flexible stone apron. The final length and shape of the island will be determined by physical model studies to suit the site requirements.

5.3.6 Gabions Retaining Walls

In hilly areas the rivers usually have high gradient/velocity flows. There, it is not practicable to provide stone protection against bank erosion. For such locations the most stable structural measure is the provision of Gabions (stone crates) retaining walls. Gabions are well suited for retaining walls because of their flexibility and also to make full use of readily available local stone. Gabions retaining walls are designed as gravity walls and their layout, geometry and stability should be checked by the applicable design criteria described under Section 9. The walls will be well extended landward into the bank line, at both ends, to avoid any outflanking during high flood.

The typical plan and cross-section of Gabion retaining wall are given in Figure 5.14.

5.3.7 Submerged Sills

When a mid-channel bar (or bela) in the river has grown over the years, it bifurcates the river channel in two separate channels flowing around the bar. One of these two meandering channels may flow close along the bank and cause bank erosion. For controlling of such bank erosion a series of submerged sills across the channel may be placed (Ref: 5.5).

The relevant typical details are shown in Figures 5.15, 5.16 and 5.17. Submerged sills resist the flow in the channel along the bank and cause the mid-channel to scour and increase its discharge. Between the sills the flow velocity reduces and sediment deposition increases. After several low to medium floods the channel between the sills becomes silted up. At that stage the bar would get attached to the bank and bank erosion would stop. The height of the sills should be the same as the height of the sand bar. The main body of the sill will be constructed with well compacted river bed material, top covered with gunny bags. The crest down to berms end will be provided with stone pitching underlain with graded spall layer.

During the rising stage water will start to flow through the notch in the third (downstream) sill and fill the area between this sill and second (middle) sill. At a slightly higher stage also the area between second (middle) sill and the first (upstream) sill will be filled through the notch in the second (middle) sill.

For particular sites the performance of the submerged sill will need to be checked by physical model studies.

5.3.8 Diversion Bunds and Cunnettes

When meandering of the river to extreme the land between the bends may gradually reduce to a narrow neck. Unless the banks of the neck and meandering river loop are protected, continuous caving takes place. The narrowing of the neck reaches a limit and a natural cutoff may form across the neck. Based on this natural phenomenon an artificial pilot cut (or cunnette) may be formed to bypass the meandering river loop and stop the banks erosion. The entry of the flow in the meandering river channel is checked by placing upstream and downstream diversion bunds. The typical layout of diversion bunds and cunnette is shown in Figure 5.18.

The cunnette is made in dry season to carry about ten (10) percent of the flood discharge and is permitted subsequently to develop to carry total flood discharge. These channels normally widen in two to three years and gradually alter the river regime.

The diversion bunds will be sufficiently anchored into the river banks to avoid outflanking. The cross-section of the diversion bunds will be similar to the cross-section of earthen marginal bund, shown in Figure 5.2. The bunds height will be designed enough to check the backwater effect in the blocked river channel. The backwater effect will be higher at bund 1 (upstream) than at bund 2 (downstream). The bund 2 (downstream) will have less design height than the bund 1 (upstream).

5.4 Design Criteria

5.4.1 Freeboard

In the design of water containing structures the crest of the embankment is to be kept higher than the level of water to be contained. This margin is necessary for safety against overtopping due to rise in water levels on account of disturbances in water from breaking waves and wind set-up in river ponds. At river curves the river set (or superelevation) also needs consideration. Where river bed accretion is regular due to sediment deposition (like in the lower reaches of Indus River) the design flood level is established by adding two feet to the recorded high flood level (Ref: 5.6). For other cases some small freeboard margin is also necessary for contigent requirement as factor of safety. Zaidi has recommended (Ref: 5.7) the following formulae for calculating the wave run-up, wind set-up and river set:

a) *Wave Run-Up (or Ride)*

The run-up (or ride) of a breaking wave in shallow water measured vertically above the mean water surface level can be estimated by Hunt formula:

$$\frac{R}{H} = \frac{K \tan \alpha}{(8/T)(H/2g)^{1/2}}$$

where:

R = wave run-up (or ride) (ft.)
H = wave height (ft.)
K = surface roughness coefficient for the embankment slope (ft.)
= 2.3 ft. for smooth surface
= 1.8 ft. for earthen surface
T = wave period (s)
α = embankment slope angle with horizontal (degree)
g = acceleration of gravity (ft./s^2)

b) *Wind Set-Up*

An appreciable rise in water level may be caused on one slope of reservoir or pond by wind action, particularly in shallow water. The wind set-up can be estimated by Zuider Zee formula:

$$S = \frac{U^2 F}{1400D} Cos\theta$$

where:

S = set-up above still pond level (ft.)
U = wind velocity (mile/hour)
F = fetch (mile)
D = average water depth (ft.)
θ = angle of fetch and wind (degree)

For combined effect of wind set-up and wave run-up the total rise in water level is equal to wind set-up plus two third of wave run-up.

c) *River Set*

At curves the deepest point of the river cross-section is near the concave (or outer) bank and the water surface there is higher than at the convex (or inner) bank. The "river set" may cause a superelevation of the water surface at the concave (or outer) bank and this can be estimated by Schoklitsch formula:

$$h = 2.3\frac{V^2}{g}.\log\frac{R_2}{R_1}$$

where:

h = river set (ft.)
V = average velocity at the upstream straight reach (ft/s)
g = acceleration of gravity (ft./s^2)
R_1 = radius of curvature of convex (or inner) bank (ft.)
R_2 = radius of curvature of concave (or outer) bank (ft.)

The "Government of Sind Bund Manual" (Ref: 5.6) indicates that "river set" may cause a rise of the water surface at the concave (or outer) bank as much as 2.0 feet (0.6 m).

d) *Recommended Freeboard*

Sufficient freeboard should be provided above the design flood level for safety against overtopping. For arriving at appropriate freeboard, the design flood level, the wave run-up, wind set-up and river set be calculated. These figures should be added accordingly and one foot additional freeboard be provided for contingent requirement as factor of safety.

The ultimate foundation and fill settlement will be neglected against one foot contingent provision.

By keeping in view the current local practices on freeboard for the typical flood protection structures, influenced by different hydraulic conditions and design wind velocity over land (U_{land}) assumed as minimum 50 miles/hour (80 km/hour), the recommended minimum freeboard provisions for various flood protection structures are given in the table below:

Flood Protection Structure	**Hydraulic/ Wind Conditions**	**Recommended Minimum Freeboard (ft.)***
CONTAINING STRUCTURES		
- Flood Bunds	Current flow, sediment deposition, wave run-up and wind set-up	6.0 (1.8 m)
- Retired Bunds	Current flow	5.0 (1.5 m)
- Marginal bunds (at barrages, bridges and syphons)	Current flow, sediment deposition, wave run-up and wind set-up	7.0 (2.0 m)
TRAINING STRUCTURES		
- Rivers bank protection	Current flow, river set, sediment deposition, wave run-up and wind set-up	Straight & convex bank=6.0 (1.8 m) Concave bank=7.0 (2.0 m)
- Spurs/Groynes	Current flow and sediment deposition	5.0 (1.5 m)
- Studs	Current flow	5.0 (1.5 m)
- Guide banks	Current flow, sediment deposition, wave run-up and wind set-up	7.0 (2.0 m)
- Pitched Islands	Current flow, wave run-up and wind set-up	5.0 (1.5 m)
- Gabions Retaining Walls	Current flow	5.0 (1.5 m)
- Sills	Current flow and back water effect	4.0 (1.2 m)
- Diversion Bunds	Back water effect	4.0 (1.2 m)

(*) The recommended minimum freeboard values include one foot additional freeboard for contingent requirement as factor of safety.

5.4.2 *Slope Stability*

The slopes of the embankment must be stable under all conditions of construction, design flood discharge, rapid flood draw-down, low flow level and earthquake forces. The stability depends on the strength of the fill soil and foundation characteristics. Similarly, the river banks needing protection will be designed for stable slopes.

Slope stability analysis requires a comparison between the state of stress in the soil and soil shear strength along an assumed failure plane. The detailed slope stability analysis will be carried out according to Method of Slices, by using Simplified Bishop Method with computer package. The needed information will include the:

- Geometry of embankment
- Soil properties
- Design flood level and low water level of the river
- Phreatic line and pore water pressure
- Surcharge on the embankment
- Earthquake loads

a) *Geometry of Embankment*

The calculations will be carried out according to the typical cross-section of the embankment for two different geometries:

- The river-bed stone apron is intact and taken into account
- The scour of the river bed is modelled with assumed fully launched stone apron

b) *Soil Properties*

The following soil parameters will be derived from laboratory tests:

- Bulk density.
- Saturated density.
- Cohesion “c”
- Angle of internal friction “ϕ”
- Unconfined shear strength
- Permeability “k”

c) River Flow Levels

The design flood level and low flow level of the river will be established for the particular embankment site to determine the phreatic surface (flood condition) and subsequent draw-down (low flow condition).

d) Phreatic Surface and Pore Water Pressure

i. *Phreatic Surface*

For a homogeneous embankment the phreatic surface is independent of fill material properties and depends solely upon the geometry of and differential head across the embankment. However, in case of more permeable fill material it will take less time to develop as compared to materials having less permeability. The position of emergence of the phreatic surface on landside slope is not influenced by the permeability of the homogeneous fill material. The less pervious material will take longer to attain the steady state position, but the ultimate position of the phreatic surface in all cases will be the same. The location of the phreatic surface (or hydraulic gradient) in the embankment will be determined for the relevant seepage condition at the design flood level, by using Casagrande's Solution (Ref: 5.8), illustrated in Figure 5.19. The two Casagrande equations are:

$$S = \sqrt{h^2 + d^2}$$
$$a = \sqrt{d^2 + h^2} - \sqrt{d^2 - h^2 \cot^2 \alpha}$$

where:

S = length of parabolic line of seepage (or phreatic line) from riverside water entrance point to the toe of landside slope (ft)

h = design flood depth on riverside slope (ft)

d = horizontal distance from riverside water entrance point to the toe of landside slope (ft)

α = landside slope angle with horizontal (degree)

a = length of surface of seepage upward from the toe landside slope (ft)

The phreatic surface will be taken as boundary between the below saturated and above dry embankment soil properties for use in the stability analysis of side slopes.

For non-homogeneous embankment or where the fill material and foundation permeabilities vary significantly, the position of the phreatic surface can vary significantly. In these cases a flow net can be constructed manually or by computerized methods.

ii. *Pore Water Pressure*

Pore pressure ratio (r_u),which is defined as the ratio of pore water pressure to vertical load at the base of each slice, will be used for the slip circles analysis for all given conditions except for riverside slope at flood draw-down condition. For this condition only pore water pressure will be used. The pore water pressure equation is:

$$u = r_u.\gamma.h$$

where:

u = pore water pressure

r_u = pore pressure ratio

γ = total unit weight of soil (dry weight above phreatic line and saturated weight below phreatic line)

h = depth of soil from top surface

e) *Surcharge*

A surcharge of 200 lb/ft^2 (975 kg/m^2) on the top surface of embankment will be applied for stability analysis.

f) *Earthquake Load*

For analysing the stability of embankments under earthquake loading a pseudostatic acceleration due to earthquake will be adopted. This will be equal to fifty percent (50%) reduction of the maximum predicted horizontal and vertical earthquake acceleration. For example, the effect of a maximum ground acceleration (in central Punjab area) due to an Operating Earthquake (OBE) of 0.12g in the free field will be equated for the stability analysis to be:

Horizontal acceleration = 0.06g

Vertical acceleration = 0.03g

These earthquake forces will act at the center of gravity of the slice.

For OBE values no major damages may be expected for the hydraulic structures in general. The OBE values for particular scheme will be adopted on the basis of specific related earthquake zone criterion.

g) *Critical Conditions for Stability Analysis*

The stability analysis of the embankment will be carried out by using laboratory test values and characteristics of selected materials for determining the "Safety Factors" under critical conditions relating to the various parameters under design requirements. The recommended minimum safety factors against shear failures are given in the table below:

Condition	**Minimum Safety Factor**	
	Without Earthquake	**With Earthquake**
During and end of construction	1.4	1.2
Rapid river draw-down	1.3	1.1
River low flow level	1.2	1.0
Design flood	1.5	1.2

For overall stability of the embankment, during construction stage and under different river flood levels, the proposed slopes of the embankment will be analysed for the stability under the following three loading conditions :

- Gravity
- Seepage (or pore water pressure)
- Earthquake

The potential failure surfaces will be analysed for the following four critical conditions against the pore water pressure by considering gravitational loading with and without earthquake:

- End of construction
- Design flood level with steady seepage
- Flood draw-down
- Assuming fully launched stone apron

The assumptions for the development of pore water pressures for the four conditions are:

i. *End of Construction*

For the end construction condition, full pore water pressure will be considered for the embankment fill.

ii. *Design Flood Level with Steady Seepage*

The critical condition for the landside slope will occur from the water seepage through the embankment when high river discharges have continued for a sufficient period. The pore water pressure development will be calculated with respect to phreatic surface within the embankment at design flood level (DFL) and with nil water level on the landside. For this condition the stability at the landside slope will be checked for steady seepage.

iii. *Flood Draw-down*

The critical condition for the riverside slope will occur as the DFL is down to the low flow level during the flood season having high saturation level at the embankment (i.e. close to DFL)

iv. *Assuming Fully Launched Stone Apron*

The applied condition will be same as item (iii) above.

The complete slope stability analysis of embankment will cover the different cases using various combinations of data input, as shown in the table on next page.

5.4.3 *Foundation Stability*

The stable side slopes of embankment depends upon the strength of the fill material and foundation characteristics. The foundation soil determines the rate of under seepage, formation of boils on the landside natural surface, the settlement of the embankment and stability of side slopes. Detailed subsurface investigations will be needed for proper foundation evaluation. If required, the particular foundation will be treated for its strengthening / protection by developing specific design to suit the site conditions. These specific designs may include:

- Reworking of the foundation soil
- Grouting of the armoured river bed to the required extent
- Inverted filter or geo-textile layer at the foundation of revetment / gabion hydraulic structure
- Where required, provision of a suitable cutoff

COMBINATIONS OF DATA INPUT FOR SLOPE STABILITY ANALYSIS OF EMBANKMENT

Sr. No	Case	Side Slope	Soil Properties	Earth-quake	Surcharge (lb./ft²)	Pore water Pressure	Remarks
	END OF CONSTRUCTION						
1	Riverside	H;V	fill	-	200	r_u	construction "r_u" important
2	Landside	H:V	fill	-	200	r_u	construction "r_u" important
3	Earthquake – Riverside	H:V	fill	H & V	200	r_u	earthquake important
4	Earthquake - Landside	H:V	fill	H & V	200	r_u	earthquake important
	RAPID RIVER DRAW-DOWN						
5	Riverside	H:V	fill	-	200	pore water pressure contours	pore water pressure important
6	Earthquake –Riverside	H:V	fill	H&V	200	pore water pressure contours	earthquake important
7	Launched Stone Apron – Riverside	H:V & assumed launching slope.	fill & subsoil	-	200	pore water pressure contours	pore water pressure important
8	Earthquake-Launched Stone Apron – River side	H:V & assumed launching slope.	fill & subsoil	H&V	200	pore water pressure contours	earthquake important
	RIVER LOW FLOW LEVEL						
9	Riverside	H:V	fill	-	200	r_u	For major part of structure life
10	Landside	H:V	fill	-	200	r_u	For major part of structure life
11	Launched Stone Apron – Riverside	H:V & assumed launching slope.	fill & subsoil	-	200	r_u	For major part of structure life
	DESIGN FLOOD						
12	Landside	H:V	fill	-	200	r_u	"r_u" important
13	Earthquake - Landside	H:V	fill	H&V	200	r_u	earthquake important

Distribution of foundation pressures will also be checked against the bearing resistance of formation soils.

The foundation investigations will be planned to provide information about the type and nature of the materials in the river bed, the depth and extent of possible openwork/surface armoured layers in the formations and rock level below the alluvium. These investigations will include possible boreholes, excavation of test pits, trenches and field and laboratory testing.

As a general rule the extent and depth of investigation depends upon the importance and height of embankment above the river bed level. It will be desired that a subsoil depth equal to about the proposed height of embankment should be investigated through test pits and boreholes. Investigations in the river bed will be confined to periods of low river flows when the drilling and other auxiliary equipment could be mobilized and deployed in the river bed. The investigation will essentially provide the following information:

- Material type and zoning
- Permeability of river bed material
- In-situ density
- Hardness of cobles and boulders
- Bearing pressure capacity

5.4.4 *Hydraulic Gradient*

After the size of flood embankment has been established with a given top width and side slopes, the existing practice is to test the cross-section against hydraulic gradient and if found necessary, back berm (or pushta) is provided to keep the hydraulic gradient within the cross-section. The hydraulic gradient is an assumed line of saturation in the embankment body. Normally, for common soils it is assumed as 6:1 and 2 feet (0.6 m) minimum cover is provided over this line as pushta if it exits on the landside.

The present practice of providing pushta on landside, however, does not adequately solve the problem of seepage flow through embankments placed on impervious foundation. Such provisions are only advisable where the duration of steady flood level against the embankment is not more than the period of saturation required for the cross-section with respect to the permeability of the fill material. Cases where duration of flood water standing against an embankment is more than the required period of saturation the provision of pushta will simply increase the period to a limited extent and does not ensure safety of the structure against piping. The position becomes more grave when the foundation of embankment is impervious. In such cases adequate provision for drainage is necessary for the safety of embankment. For embankments that remain in contact with flood water for a prolonged period, the phreatic line will be established for designing of the embankment to the phreatic line concept.

Based on the above discussion the embankments will be divided in the following two categories:

- Embankments which come in contact with the flood water for short duration.
- Embankments which remain in contact with the flood water for long periods.

For the first category, it is recommended to design the embankments on the basis of hydraulic gradient line as per current practices. The second category of embankments will be designed by ensuring stability of slopes and preventing their failure through piping.

When fill material of the embankment is not sufficiently homogeneous the flood water may reach the landside slope with a sufficient hydraulic head to cause instability or piping of the fill material. This may result in complete breaching of the embankment. In such cases a horizontal drainage layer will be designed to deliver the seepage water safely to the landside toe of the embankment. A rock toe may be provided at the landside slope.

The introduction of landside filter will establish a definite exit for the seepage water. Landside toe of the embankment will not become wet and pushta will no longer be needed. Also, the piping and internal erosion of the embankment will be controlled and chances of embankment breaches due to these factors will be minimized.

The drainage layer shall be selected to be free draining as well as maintaining filter compatibility with the embankment fill. In general for filteration:

$$\frac{d_{15}\,filter}{d_{85}\,base} \leq 5$$

Where the base can be embankment fill or the foundation material under the filter.

For drainage:

$$\frac{d_{15}\,filter}{d_{15}\,base} > 5$$

In some cases, the drainage layer may consist of a coarse granular material enveloped by a filter material.

5.5 *Hydraulic Model Studies*

Normally, two hydraulic model studies using physical models will be carried out to investigate various aspects of the overall performance of the proposed guiding / protection structures forming the scheme, as follows:

Model 1 - Comprehensive model of the scheme at appropriate geometric scale, to refine the design of the proposed river training works. Generally, the results obtained would be transferred quantitatively, with simple laws of similarity, to the prototype.

Model 2 - Distorted movable river bed model covering the predetermined river reach, at appropriate vertical and horizontal scales. This model will optimise the configuration, scour protection, velocity and other details of the proposed river training works.

The models will be constructed from a general layout plan, bathymetric and topographic data of cross-sections at predefined locations and details of any existing and new proposed structures. These models will obtain the effectiveness of the scheme on stabilization of the river and also, point out in this respect any required deviation from the proposed designs. The main hydraulic design components for checking by the model studies are:

- Overall effectiveness of the scheme; the anticipated check on the erosion of river banks and that of the proposed number, location, configuration and types of the designed structures.
- Any addition or subtraction; in the proposed number of the structures to optimise the effectiveness of the scheme.
- River flow depths; for varied discharges.
- River varied discharges; are guided well by the scheme at all fluctuating flow levels.
- Check, refine and optimise; the geometry, relative location and configuration of individual structure and in combination with other structures.
- Local scour pattern; along the structures for confirming the optimum level and sufficiency of flexible stone launching aprons.
- Maximum velocity; along the structures for confirming the median stone size designed for apron and revetment stability including its underlain filter layers. Also, to check the sufficiency of armoured head of the structure, if any.
- Development of cunnette; if any, provided within the scheme.

- Sediment deposition; anticipated pattern and concentration locations within the scheme.

5.5.1 *Model Scales Relation*

For geometric models the accepted hydraulic equations, based upon Froude's law, will be used to express the mathematical relations between the dimensions and hydraulic quantities of the model and prototype. The general relations expressed in terms of the recommended model scales (or length ratio "Lr") are given below (Ref: 5.3):

Dimensions	**Ratio**	**Scale Relation**
Length	L_r	1:40
Area	$A_r = L_r^2$	1:1600
Weight	$W_r = L_r^3$	1:64000
Volume	$V_r = L_r^3$	1:64000
Velocity	$\nu_r = L_r^{1/2}$	1:6.33
Discharge	$Q_r = L_r^{5/2}$	1:10128
Time	$T_r = L_r^{1/2}$	1:6.33

References

5.1 Ayoob S.M. and Ali C.M., Alignment and Shape of A Spur Head, Proceedings of Pakistan Engineering Congress, (1975).

5.2 Verma C.V.J. et. al., River Behaviour Management and Training, Volume I, Central Board of Irrigation and Power, New Dehli, India, (1989).

5.3 Chohan M.A. et. al, Some Experiments on Shape of Spurs, CIV-CON-87/5, Institution of Engineers, Pakistan.

5.4 Sharma K.R., Irrigation Engineering, Volume I, India Printers, India, (1959).

5.5 Second Flood Protection Sector Project, Final Report, HASKONING, DELFT HYDRAULICS and NESPAK, Joint Venture Consultants, (1997).

5.6 Bund Manual, Public Works Department, Government of Sindh, (1954).

5.7 Zaidi S.M.A., Wind Generated Waves and Their Effects on River Bunds, Proceedings of Pakistan Engineering Congress. (1978).

5.8 Harr M.E., Groundwater and Seepage, McGraw-Hill Book Company, (1962).