8

Rivers, Their Behaviour, Control and Training

8.1. Importance of Rivers and Necessity of Controlling Them

Water is the most important natural resource not only of a state or of a country, but of the entire humanity. The prosperity of a nation depends primarily upon the exploitation of this resource. Thus, it can be stated that the primary wealth of a nation is water, which flows in rivers and streams. This itself establishes the importance of rivers, and no other explanation is required to stress their importance.

Importance of rivers has been recognised since time immemorial, and rivers have occupied a very prominent place in every stage of human development. With the incoming of modernisation and mechanisation of human life, water and hence, rivers are becoming more and more important. They provide us water for industrial uses and are a source of cheap energy. Rivers have always been satisfying our domestic, municipal, irrigation, and other demands, and that is why most of our cities were established in the vicinity of the natural rivers. In the primitive times, there was absolutely no control on these natural rivers, and hence, they used to cause tremendous devastations and troubles to human beings. But with the development of science and technology, and in his bid to control nature, man has devised and is devising means and ways to control these mighty rivers. In the above context, we have to study the rivers, their behaviour, and to develop means and ways, so as to ensure an effective control upon them.

Rivers take off from mountains, flow from the mountainous plain terrains, and finally join the oceans. They are formed along more or less defined channels, drain away the land water obtained by precipitation and snow melting in high altitudes, and discharge the unutilised waters back into the sea, thus completing the hydrological cycle. The rivers not only carry this huge amount of water but also carry a tremendous amount of silt and sediment which is washed down from the catchment area or gets eroded from their beds and banks. Before we discuss the techniques that are often adopted for controlling and improving the rivers, let us, first of all, discuss the various types of rivers and their characteristics.

8.2. Types of Rivers and Their Characteristics

8.2.1. Classification of Rivers on the Basis of the Topography of the River Basin. Depending upon the topography of the basin, the river reaches can be classified into two main classes, *i.e.*

(*i*) *Rivers in hills* (Upper reaches) ;

(*ii*) *Rivers in alluvial plains*, known as rivers in flood plains (Lower reaches) ; and

(*iii*) *Tidal rivers*

All these three types of river reaches are described below :

(*i*) **Rivers in Hills (Upper Reaches)**. The rivers generally take off from the mountains and flow through the hilly regions before traversing the plains. These upper reaches of the rivers may be termed as *Rivers in Hills*. They can be further sub-divided into :

(*a*) Incised or Rocky River stage ; and

(*b*) Boulder River stage.

(*a*) *Rocky Stage or Incised River Stage (Upper reaches)*. In this type, the flow channel is generally formed by the process of degradation (erosion). The sediment transported in this reach is often different from the river bed material, since most of it comes from the catchment due to denundation and soil erosion. These river-reaches are highly steep with swift flow, and forming rapids along their courses. The beds and banks of such rivers are less susceptible to erosion. The bed-load carried by such river-reaches cannot be determined on the basis of usual bed load transportation formulas, derived on the basis of bed characteristics.

(*b*) *Boulder River Stage (Upper reaches)*. The river bed in these reaches consists of a mixture of boulders, gravels, shingles and alluvial sand-deposits created by itself. Still these river reaches differ considerably from those carrying sand and silt and flowing through plains. In the latter stage, the river flows through deep well defined beds and wider flood plains and develops zig-zag courses. On the other hand, in the boulder stage, *the river flows through wide shallow beds and interlaced channels, and develops a straighter course*. During a flood, the boulders, shingles and gravels are transported downstream, but as the flood subsides, the material gets deposited in heaps. The water, then unable to shift these heaps, go round them, and the channel often wanders in new directions, often attacking the banks and consequently widening the bed.

(*ii*) **Rivers in Alluvial Flood Plains (Lower Reaches)**. The chief characteristics of these river reaches is the zig-zag fashion in which they flow, called **meandering**. They meander freely from one bank to another and carry sediment which is similar to bed material. Material gets eroded constantly from the concave bank (outer edge) of the bend and gets deposited either on the convex side (inner edge) of the successive bends or between two successive bends to form a bar, as shown in Fig. 8.1.

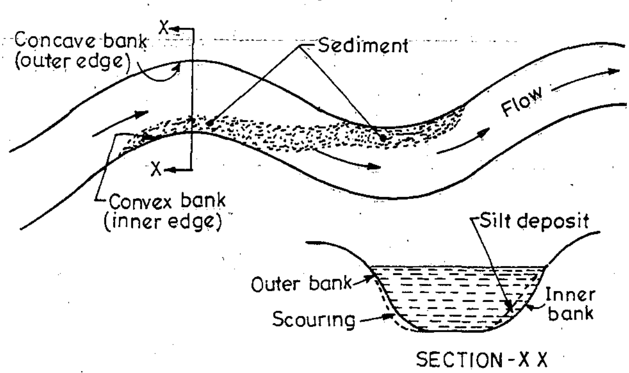


Fig. 8.1. Silting and scouring in a meandering river.

When once a straight moving river, just slightly deviates from its axis, the unbalance created goes on multiplying *with constant erosion from the concave side and deposition on the convex side*. If unchecked, the process continues, resulting in the formation of large meanders.

Rivers in flood plains can be further classified as :

(*a*) *Aggrading* ; (*b*) *Degrading* ; (*c*) *Stable* ; (*d*) *Braided* ; and (*e*) *Deltaic*.

If the river is collecting sediment and is building up its bed, it is called an *aggrading* or of an *accreting type*. If the bed is getting scoured year to year, it is called a *degrading type*. If there is no silting or scouring, it is called a *stable river*. It is not necessary that a river reach should be of one type in its entire alluvial length, rather it is generally of more than one type of reach, in its length. In other words, the same river reach may behave as of aggrading or of degrading or of stable type. How and under what circumstances, the river may change its type, will become very clear, if we study these types in details, as given below :

(*a*) *Aggrading or Accreting Type*. An **aggrading river** is a silting river, as shown in Fig. 8.2. Such a river increases its bed slope, which is called *building up of slope*. The silting may be due to various reasons, such as heavy sediment load; construction of an obstruction across the river, such as a dam or a weir; sudden intrusion of sediment from a tributary; etc. This type of river, usually, has straight and wide reaches with shoals in the middle, which shift with floods, dividing the flow into a number of braided channels.

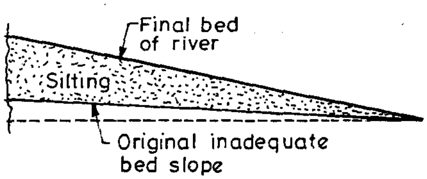


Fig. 8.2. Aggrading River

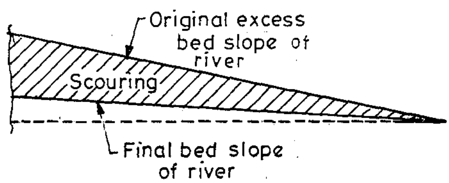


Fig. 8.3. Degrading River.

(*b*) *Degrading Type*. If the river bed is constanly getting scoured (eroded) to reduce and dissipate available excess land slope, as shown in Fig. 8.3, then the river is known as a **degrading river**. It may be found either above a *cutoff** or below a dam or a weir or a barrage, etc. For example, the Colorado River (U.S.A.) became a degrading type on the downstream, after the construction of the Boulder dam.

(*c*) *Stable Type*. A river which does not change its alignment, slope and its regime significantly, is called a *stable river*. Changes such as silting or scouring or advancement of delta into the sea may take place, but they are negligible and may fail to produce any change in the regime of the channel, except, perhaps, that the river may shift within its *Khadirs***. Most of the sediment load carried by them is brought to the sea.

The behaviour of a particular reach (whether to be aggrading, degrading or stable) depends mainly upon the variations of silt charge (size as well as quantity) and flow discharge with time.

(*d*) *Braided Rivers*. When a river flowe in two or more channels around alluvial islands (as shown in Fig. 8.4), it is known as a **braided river.**

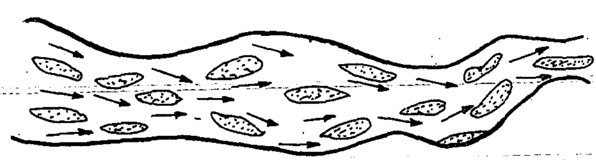


Fig. 8.4. A typical braided reach of a river.

The braided pattern in a river develops after local deposition of coarser material, which cannot be transported under prevailing conditions of flow, and which subsequently grows into an island consisting of coarse as well as fine material.

* Explained later.

** The extreme limits within which a river is known to have ever wandered.

(*e*) *Deltaic Rivers.* A river before it joins the sea, gets divided into branches, thus forming a Δ shaped delta, as shown in Fig. 8.5.

As the river approaches the sea, its velocity is reduced, and consequently the channel gets silted and water level rises resulting in spills and eventual formations of new channels. These branches multiply in their number as the river approaches the sea. Causes of delta formation and factors responsible for its shape and growth etc., are beyond the scope of this book. The **delta river** indicates a stage, rather than a type of a river.

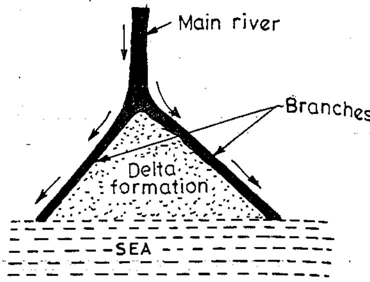


Fig. 8.5. Delta formation.

(*iii*) **Tidal Rivers**. The tail reaches of the rivers adjoining the oceans are affected by the tides in the ocean. The ocean water enters the river during the flood tide and goes out into the ocean during the ebb tide. The river, therefore, undergoes periodical rise and fall in its water level, depending upon the nature of the tide. The distance upto which the tidal effect is experienced, depends upon various factors, such as the shape and configuration of the river, the tidal range, freshet discharge, etc. The detailed description of tidal reaches is beyond the scope of this book.

8.2.2. Classification of Rivers on the Basis of Flood Hydrographs. The rivers may be classified on the basis of stage and nature of their flood hydrograph, into the following two types :

(*i*) Flashy rivers ; and (*ii*) Virgin rivers.

(*i*) **Flashy Rivers**. If the flood rise and flood fall in a river is sudden, then it is called a *flashy river*. In flashy rivers, the flood flows, therefore, occur suddenly, and rise and fall of water level is very quick. The flood hydrographs are very steep, indicating floods, all of a sudden.

(*ii*) **Virgin Rivers.** In arid zones (deserts), a river water may completely dry before it joins another river or the ocean. Such a river is called a *virgin river*. After flowing for a certain distance from its source, the water of such a river disappears due to high percolation or due to excessive evaporation. There are several virgin rivers in the States of Kutch and Rajasthan in India.

8.3. Indian Rivers and Their Classification

Indian rivers can be broadly classified into :

(*i*) *Himalayan rivers* ; and

(*ii*) *Non-Himalayan rivers.*

(*i*) **Himalayan Rivers**. These rivers take off from Himalayas and flow through alluvial plains. They derive their water from rains during monsoon and winter, and from the melting snow during summer. These rivers are, therefore, almost perennial and can give dependable yields throughout the year. These rivers carry huge sediment, because of two reasons : (*i*) The Himalayan rocks are soft and friable (*ii*) The Himalayan zone, particularly the north-eastern part, is susceptible to earthquake disturbances, causing landslides and increased rock sediment. The important Himalayan rivers are :

Indus, Jhelum, Chinab, Ravi, Beas, Sutlej, Ganga, Gandak, Ghaghar, Gomti, Kosi, Brahmaputra, etc.

Due to the heavy rainfall in the month of July and August (causing about $\frac{3}{4}$th of average annual rainfall), these North Indian rivers rise in high floods. The surface runoffs so caused are usually much more than the normal average flow of the entire year. The flood discharge may be as great as 50 to 100 times the normal winter flow. The sections required for passing flood discharges are vastly out of proportion to the sections required for normal winter flows. These large variations in discharge and sediment load make the hydraulics of these rivers very complex and cause them to meander.

(ii) **Non-Himalayan Rivers.** They are non-perennial rivers. They receive their major water supply only in rainy seasons ; and for the rest of the year, they may draw water from ground water as base flow. They flow in Central and South India and takeoff from Aravali, Vindhya and Satpura mountain ranges. *Chambal, Mahanadi, Cauvery, Godavari, Tapti, Narmada, etc.*, are the important examples of these rivers. These rivers are much more stable than the Himalayan rivers, and pose lesser problems, as they flow through non-alluvial soils. The dividing line between Himalayan & Non-Himalayan rivers is the boundary hetched by the left bank of river *Sutlej*, Right bank of river *Yamuna* and *Ganga* (after Allahabad) and left bank of river *Brahmaputra*, as can be seen in the map of Indian rivers, shown in the enclosed coloured photo Fig. 8.1.

Note : For regional classifications of Indian rivers, please refer article 1.5 in "Hydrology and Water Resources Engineering" by the same author.

8.4. Behaviour of Rivers

The chief factor which is responsible for moulding the behaviour of rivers is the silt and sediment that flows in the river. The sediment carried by the river poses numerous problems, such as : increasing of flood levels, silting of reservoirs, silting of irrigation and navigation channels, meandering of rivers, splitting up of a river into a number of interlaced channels, etc. The *meandering* causes the rivers to leave their original courses, forces them to flow along new courses, and thus devastating vast areas of land and affecting important and valuable nearby structures, such as bridges, railway lines, roads, etc. We shall now discuss the behaviour of the rivers in special situations, such as in bends, meanders and cutoffs, in details.

8.4.1. Straight Reaches. In a straight reach of a river, the river cross-section is in the shape of a trough, with high velocity flow in the middle of the section.

Since the velocity is higher in the middle, the water surface level will be lower in the middle and higher at the edges, as shown in Fig. 8.6. Due to the existence of this transverse gradient from sides towards the centre, transverse rotary currents get developed, as shown in Fig. 8.6. However, straight reaches are very few in alluvial rivers.

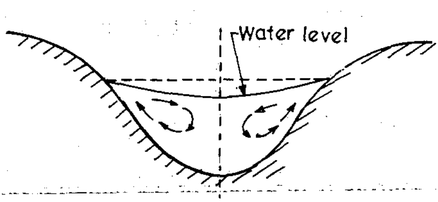


Fig. 8.6

8.4.2. Bends. Every alluvial river tends to develop bends, which are characterised by scouring on the concave side and silting on the convex side, as shown in Fig. 8.7. The silting and scouring in a bend may continue due to the action of the centrifugal force.

When the flow moves round a bend, a centrifugal force is exerted upon the water, which results in the formation of transverse slope of water surface from the convex edge to the concave edge, creating greater pressure near the convex edge (see Fig. 8.7). To keep its own level, water tends to move from the convex-side towards the concave side.

However, the topmost water surface movement is prevented by the centrifugal force. Moreover, towards the bottom, the velocities are much less than towards the top, and enough centrifugal force is not available to counteract the tendency of water at the top to move inwards. Hence, the water dives in, from the top at the concave end, and moves at the bottom towards the convex end. These rotary currents cause the erosion of concave edge and deposition on convex edge, forming shoals on the convex sides. When once a bend is formed, the flow tends to make the curvature larger and larger.

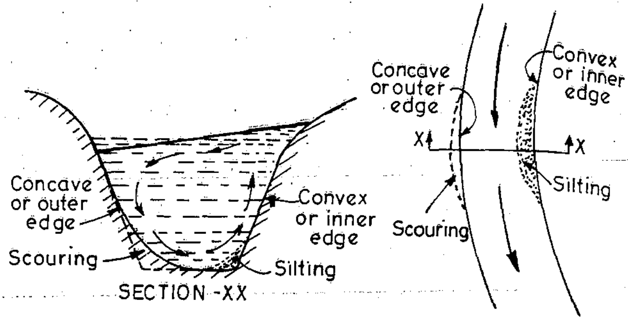


Fig. 8.7

8.4.3. Meanders. When once a river deviates from its axial path and a curvature is developed (either due to its own characteristics or due to the impressed external forces), the process moves downstream by building up shoals on the convex side by means of secondary currents. The formation of shoals on the convex side, results in further shifting of the outer bank by erosion on the concave side.

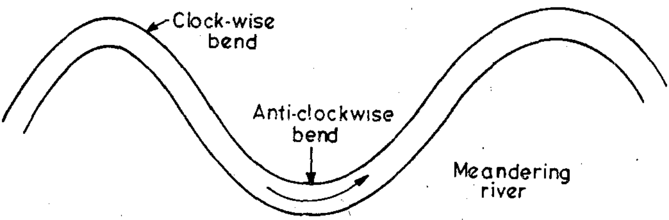


Fig. 8.8. Meandering River.

Formation of successive bends of reverse order may lead to the formation of a complete S curve called meander. When consecutive curves of reverse order connected with short straight reaches called (crossings) are developed in a river reach, the river is stated to be a meandering river (Fig. 8.8). In order to study the behaviour of a meandering river, the river may be supposed to follow a *sine curve.*

Causes of meandering. There was a belief that meandering is caused due to the presence of an excessive bed slope in the river that the excess energy is dissipated by increasing the channel length by meandering. The above theory has been proved to be incorrect.

The latest and widely accepted theory behind meandering is based upon the extra turbulence generated by the excess of river sediment during floods. During floods, the river carries tremendous amount of silt charge. *It has been established that when the silt charge is in excess of the quantity required for stability, the river starts building up its slope by depositing the silt on its bed. In other words, the river reach becomes an aggrading or of an accreting type. This accretion, is the primary process, which consequently leads to meandering, as explained below :*

The increase in river slope tends to increase the width of the channel, if the banks are not resistant. The banks are, thus, attacked by water, and in the process, one bank is likely to be attacked slightly more than the other, causing a slight deviation of flow. This slight deviation from uniform axial flow, *helps in moving more and more flow towards one bank than towards the other.* The process continues with more and more vigour, causing more and more flow towards the former bank and forming shoals along the latter, thus, accentuating the curvature of flow, and finally, producing meanders in its wake.

The concave bank goes on eroding and the convex bank goes on silting. Further, it has been established that collection of sediment on the convex side is independent of the concave side happenings, and deposition and formation of convex shoals will continue, irrespective of what happens on the concave side. When the concave side is rivetted, or pitched, the river gets deepened as the convex bar continues to progress towards the pitching. Due to the shift of the convex bar, the width between the banks reduces, which increases the velocity, and thus provides a current strong enough to prevent further, extension of convex-bar. In that case, the extension of shoal towards concave side is stopped, but the shoal continues to gain in height.

There are four variables, which govern the meandering process. They are : (*i*) Valley slope, (*ii*) Silt grade and silt charge, (*iii*) Discharge, (*iv*) Bed and side materials and their susceptibility to erosion. All these factors considerably affect the meandering patterns, and all of them are interdependent. On the basis of this theory and experiments, various empirical formulas have been developed for connecting various meander parameters ; *but much remains to be learnt about the meander process.*

Meander parameters. The various meander parameters are shown in Fig. 8.9, and are defined below :

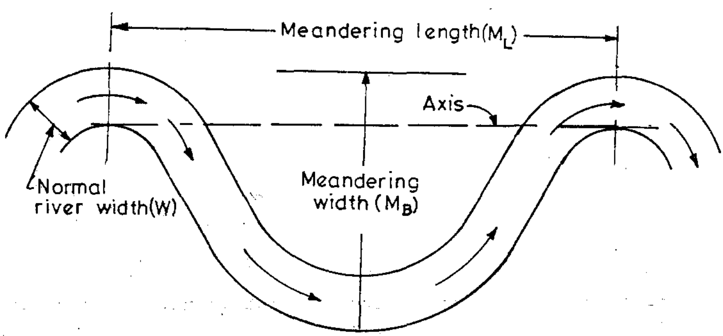


Fig. 8.9. Meander Parameters.

Meander Length (M_L). It is the axial length of one meander, *i.e.* the tangential distance between the corresponding points of a meander.

Meander Belt (M_B). It is the distance between the outer edges of clockwise and anti-clockwise loops of the meander.

Meander Ratio. It is the ratio of meander belt to meander length, *i.e.* $\frac{M_B}{M_L}$

Tortuosity. It is the ratio of the length along the channel (*i.e.* arcual length) to the direct axial length of the river reach.

Crossings or Cross-overs. The short straight reaches of the river, connecting two consecutive clockwise and anti-clockwise loops, are called crossings or cross-overs.

Experiments have been and are being conducted, so as to establish some reliable relationship between these parameters.

A large data on Indian rivers was collected by Jefferson and analysed by Inglis, on the basis of which, he was able to give the following tentative relationship-between different parameters :

Table 8.1

Rivers in flood plains (where W is the river width)	*Incised Rivers (Rocky Rivers in hills*)*
$M_L = 6.06\, W$	$M_L = 11.45\, W$
$M_B = 17.40\, W$	$M_B = 27.3\, W$
$M_B = 2.86\, M_L$	$M_B = 2.2\, M_L$
$M_L = 53.6\, Q^{1/2}$	$M_L = 46\, Q^{1/2}$
$M_B = 153.5\, Q^{1/2}$	$M_B = 102.3\, Q^{1/2}$
$W = 8.85\, Q^{1/2}$	$W = 4.53\, Q^{1/2}$

It is generally observed that the total length of a meandering river along the channel remains more or less the same from year to year. If the length is shortened by the development of a cut-off, the original length is regained by rapid erosion and increase in meander belt downstream of cut-off.

It has also been found that the steep rivers meander to a lesser extent compared to those with flatter gradients.

The extent of turtuosity was found to vary throughout the course of the river. How the tortuosity varies, from the point a river becomes alluvial down to its mouth, can be estimated from the meandering of Ganga from Balawalli to the sea, as shown in Table 8.2.

Table 8.2

S.No.	*River reach*	*Direct length in km*	*Length along the channel in km*	*Percentage of tortuosity or percentage of meander*
1.	Balawalli to Garhmukteshwar	104.0	116.8	12
2.	Garhmukteshwar to Rajghat	59.2	67.2	14
3.	Rajghat to Kanpur	280	312	11
4.	Kanpur to Allahabad	176	216	23
5.	Allahabad to Varanasi	136	208	51
6.	Varanasi to Sara	680	864	27
7.	Sara to Sea	296	320	8

For natural rivers, the discharge which determines the meander length and meander belt, may be called the *dominant discharge*. **Dominant discharge** is different from the maximum discharge, because at maximum discharge, the main flow swings away from the bend and erosion at the bank is reduced. Thus, the meander pattern is developed due to the combined effect of the discharge cycle during a flood season, and not by the maximum discharge. In most rivers, the dominant discharge varies between $\frac{1}{2}$ to $\frac{2}{3}$ of the maximum discharge. Meander length for rivers in flood plains may, therefore, be given by

$$M_L = 65.8\sqrt{Q_{dominant}} \qquad \text{...(8.1)}$$

where $Q_{dominant} = \frac{1}{2}$ to $\frac{2}{3}$ (generally 9/16) of maximum discharge.

Cut off. In an excessively meandering river, a particular bend may sometimes be abandoned by the formation of a straighter and a shorter channel (*AB*), as shown in Fig. 8.10. The process, whereby, this chord channel is developed or the chord channel itself, is termed as cut-off. It is evident that a meander increases the river length but a cut-off reduces the river length. Hence, a cut-off is a natural phenomenon for counterbalancing the otherwise ever increasing length of the river course due to the development of meanders.

* **Incised river**, as defined in article 8.21(*a*) represents rocky stage of a river in hills.

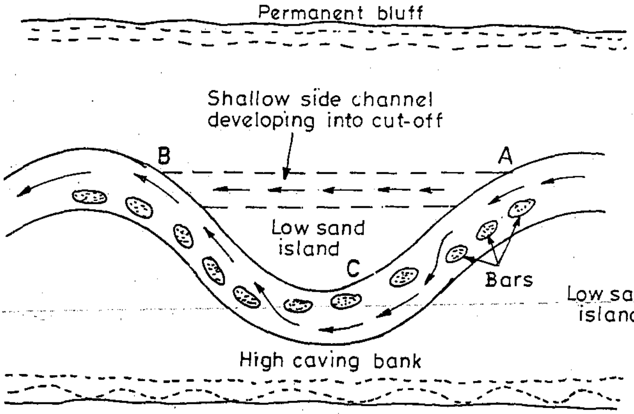


Fig. 8.10. Cut-off development.

Development of a cut-off. A meandering river flowing along the curved path has a shallow side channel besides its main curvilinear path, as shown in Fig. 8.9. This might be the remains of its old course or may be created by floods spilling over the river bank. During high floods, excessive deepening of the pools occur, and is supplemented by the growth of bars at the inflections. Both these factors tend the water to flow more and more towards the side channel. When the flow starts reducing in the main channel, more and more silting occurs in the main channel, which further increases the flow in the side channel. The process continues and finally, a time may come when the entire water starts flowing from the full developed chord channel and the curvilinear path gets silted up.

The period, over which the opening of a chord channel matures into a full-fledged cut-off may vary considerably, depending upon the local conditions. It may take six months, a year, or even five or ten years.

Whenever, a cut-off starts developing, panic and chaos is created over a certain period for miles above and below the newly formed short-cut, as the affected settlements like Jhuggis or agricultural operations, will have to be adjusted. Banks start caving, new channels are formed, old channels may get silted up, until atlast, a temporary stability is created during low floods. The period of adjustment and agitation starts again with the next flood. The process continues, until, full equilibrium conditions are established.

Cut-off ratio. The ratio of the length of the bend to that of the chord, *i.e.* *ACB/AB* (Fig. 8.10) is called the cut-off ratio. This ratio varies depending upon the characteristics of the river at site, such as the discharge, the river flood stage, surface fall, bed material and its suitability for the growth of protective grass and weeds, etc. Hence, only a certain minimum value of cut-off ratio is not sufficient for the development of a cut-off. In other words, a cut-off ratio of 1.7 to 3.0 on a certain reach may result in the formation of a cut-off, while even a cut off ratio equal to 8.0 to 10.0 may not result in the formation of a cut off on some other reach. Normally, cutoff may be developed, if the following conditions are satisfied :

(*i*) The cut-off ratio varies from 1.7 to 3.0 or more.

(*ii*) The ratio $\frac{r}{\sqrt{Q_{max}}}$ is between 13 to 24, where r is the radius of curvature of the loop (bend) ; and Q_{max} is the maximum discharge. A cut-off formation is accelerated if the curvature is too sharp for the discharge.

(*iii*) The shallow side channel is tangential to the main direction of river flow approaching and leaving the cut.

Angle of Swing. The angle of swing is the angle (in degrees) by which the river flow takes a turn (Fig. 8.11). The maximum possible angle of swing was found by Chately, to be equal to

$$\theta = 180° + 2\left[\text{Vers}^{-1}\left(\frac{\text{Chord}}{2 \times \text{Radius}}\right)\right] \quad ...(8.2)$$

This was found on the consideration that when arc/chord ratio exceeds 1.571, *i.e.* when the angle of swing exceeds 180°, conditions favourable for a cut-off are obtained.

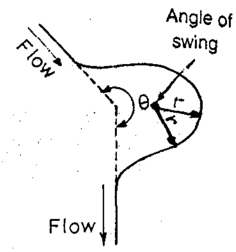


Fig. 8.11. Angle of swing.

8.5. Control and Training of Rivers

River training, in its wider aspects, covers all those engineering works which are constructed on a river, so as to guide and confine the flow to the river channel, and to control and regulate the river bed configuration, thus ensuring safe and effective disposal of floods and sediment loads. Stabilising and training the river along a certain alignment with a suitable waterway is, therefore, the first and formost aim of river training.

8.5.1. Objectives of River Training. The river training works may serve the following objectives or advantages :

(*i*) To prevent the river from changing its course and to avoid outflanking of structures like bridges, weirs, aqueducts, etc.

(*ii*) To prevent flooding of the surrounding countries by providing a safe passage for the flood waters without overtopping the banks.

(*iii*) To protect the river banks by deflecting the river away from the attacked banks.

(*iv*) To ensure effective disposal of sediment load.

(*v*) To provide minimum water depth required for navigation.

8.5.2. Classification of River Training. Depending upon the purpose for which a river training programme is undertaken, the river training works may be classified into the following three categories :

(1) High water training or Training for discharge.

(2) Low water training or Training for depth.

(3) Mean water training or Training for sediment.

(1) **High water training or Training for discharge.** High water training is undertaken with the primary purpose of flood control. It, therefore, aims at providing sufficient river cross-section for the safe passage of maximum flood, and is concerned with making the adjoining area flood-proof, by construction of dykes or levees, etc.

(2) **Low water training or Training for depth.** Low water training is undertaken with the primary purpose of providing sufficient water depth in navigable channels during low water periods. It may be accomplished by concentrating and enhancing the flow in the desired channel by closing other channels, by the process of *bandalling* by contracting the width of the channel with the help of 'groynes', etc.

(3) **Mean water training or Training for sediment.** Mean water training aims at efficient disposal of suspended load and bed load, and thus, to preserve the channel in good shape. The maximum accretion capacity of a river occurs in the vicinity of mean water or dominant discharge. Therefore, the changes in the river bed are attempted in accordance with that stage of flood flow. The mean water training is the most important type and forms the basis on which the former two are planned.

8.5.3. Methods of River Training. The chief aim of river training is to achieve *ultimate stability* of the river with the aid of river-training measures. The *stability* of a river does not mean that changes like scouring and silting of bed, advancement of delta into the sea, etc. will not take place. It only means, that the river attains an equilibrium stage, and no significant change occurs in its alignment, slope, regime, etc. The regime may change within a year but shows little variation from year to year, except that, the river may meander within its *khadirs* (*i.e.* the extreme lines within which the river is ever known to wander).

It was discussed earlier, that a river adjusts its alignment, perimeter, area, slope, etc.; with respect to the discharge and sediment load, either by aggrading, meandering or by degrading. Aggrading and meandering is one and the same thing except that aggrading is the initial stage and meandering is the final stage.

It may be concluded that meandering type is the full and final development of an alluvial river. The other two types are the interim phases and are maintained so long as the factors causing them remain operative. Aggrading rivers are, therefore, not equally amenable to river training on account of their instability. River training works undertaken on aggrading or degrading rivers may, therefore, fail to impose any stability on such rivers. For example, bank protection works undertaken on an aggrading river may either be destroyed by severe erosion or get buried under sediment deposition. *Soil conservation measures in the upper reaches and construction of check dams on tributaries are the most effective measures to be undertaken for controlling aggrading rivers,* before taking up any river training works on such rivers. Similarly, the training works undertaken on degrading rivers may fail due to scour and undermining of foundations by bed scour.

The scouring tendency of degrading rivers must be controlled *by building cross bars, weirs, etc., before attempting any other* river training works on such rivers.

The following are the generally adopted methods for training rivers, including bank protection :

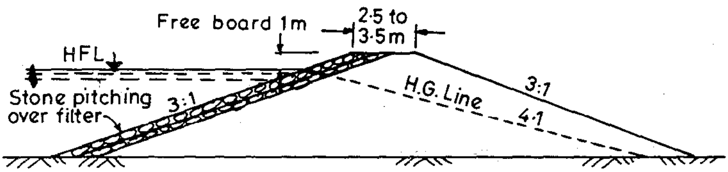
(1) Marginal embankments or Levees.
(2) Guide banks.
(3) Groynes or Spurs.
(4) Artificial cut-offs.
(5) Pitching of banks and provision of launching aprons.
(6) Pitched islands.
(7) Miscellaneous methods, such as Sills, Bandalling, etc.

(1) **Marginal Embankments or Levees.** Marginal embankments are generally earthen embankments, running parallel to the river, at some suitable distance from it. They may be constructed on both sides of the river or only one one side, for some suitable river length, where the river is passing through towns or cities or any other places of importance. These embankment-walls, retain the flood water and thus, preventing it from spreading into the nearby lands and towns. *A levee or a dyke is mainly used for flood-protection by controlling the river and not by training the river.*

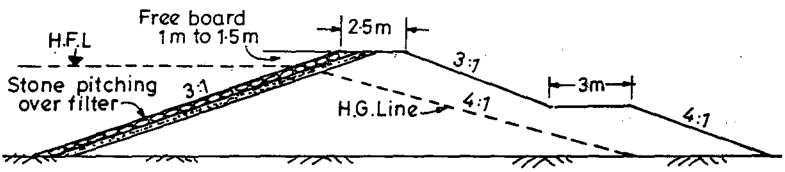
The alignment of levees should follow the normal meandering pattern of the river. The retirement of the levees has to be governed by technical as well as economical and political considerations, because the land falling within the levees, is either to be acquired by the government or remains susceptible to floods. The levees, are many a times, pitched on the upstream side (*i.e.* water side). Launching apron may also be provided, if the bank or levee is close to the main river channel.

Design of levee section. Levees are just like earthen dams with the difference that they are very long, come in operation discontinuously and for a short time, and have limited possibilities for selection of their alignment along favourable geological strata. Their sections should be designed in such a way as to keep the seepage gradient inside the body of the embankment by at least one metre from below the top surface of the embankment. The normal value of usually adopted seepage gradient varies between 4 : 1 to 6 : 1 (*i.e.* H : V) depending upon the character of the soil which may-necessitate river side slopes varying between 2 : 1 to 5 : 1, land side slopes between 2 : 1 to 7 : 1, and top width between 2.5 to 10 m. The top level of the levee should be decided by leaving a sufficient freeboard varying between 0.3 to 1.5 m above the high flood level.

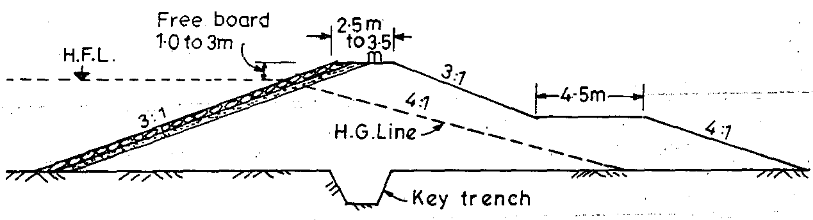
The levee sections which are usually adopted for different heights are shown in Fig. 8.12.



(*a*) For heights below 2.5 m.



(*b*) For heights above 2.5 m and upto 3.25 m



(*c*) For heights above 3.25 m

Fig. 8.12. Typical sections of levees for different heights.

Effects of levees on river bed. In order to assess the effects of dikes or levees on rivers, we shall, first of all, discuss the hydraulics of an undiked river during floods, and then discuss the hydraulics of a diked river.

During floods, water spills over the natural banks of a river. The velocity of this water will be reduced because it spreads over the adjoining land. Due to this reduction in velocity, soil gets deposited as the silt deposition varies inversely with the velocity. In an undiked alluvial river, the flood water spreads over a vast area, so that the velocity becomes so small that almost the entire silt gets deposited on the flood area, and clear water flows back into the main river as the flood recedes.

When the river is enclosed by dikes, the water spills over the natural banks of the river and will spread in the area confined between the river and the dikes. Due to this, the velocity of flow reduces and silt gets deposited. But infact, this reduction in velocity in a diked river is much less than that in an undiked river, because the spread area is less in a diked river. Hence, it can be concluded that the silt deposition will be less in a diked river compared to that in an undiked river.

At the same time, it can also be concluded that in a diked river, the silt will be deposited only in the confined fixed area (*i.e.* area enclosed between dikes and river), and therefore, the bed level of the river as well as that of this enclosed area will increase. Hence, the land enclosed between the dikes will appear to be higher than the adjoining land, and this probably leads to false common man belief that "the dikes cause ill-effect of raising the river-bed".

On the other hand, in an undiked river, the level of the entire land will increase and there will not appear any appreciable raising of the bed. Since the clear-cut raising of the bed is not generally visible on undiked rivers, people get misguided, and they feel that there was no bed rise in undiked rivers, and they become against diking stating "dikes cause the ill-effects of raising the river-bed", although it is not a correct statement.

(2) **Guide Banks.** If an engineering structure, such as, a weir or a barrage or a bridge, etc. is constructed across a river, the river width is reduced and trained in such a fashion, as to ensure not only a safe and expeditious disposal of flood water but also to ensure a permanent reasonable width of the waterway for the river flow. It has already been discussed that the alluvial rivers do shift their courses. Now, if today a structure such as a bridge, is constructed across the existing river width, the other day, the river may shift and there may not be any river below the existing bridge at all, and the river may be found to be flowing away from it, necessitating the construction of another structure. This may lead to the extension of the structure for the entire river length between its *khadirs*.

But, it is unwise and uneconomical to span the entire width of the river and to expose the structure to vagaries of attack and deep scour. Hence, a structure such as a weir, or a barrage, or a bridge, etc. is extended in a smaller width of the river, and river water is trained to flow almost axially through this trough without out-flanking the structure. The river is normally trained for this purpose with the help of a pair of guide banks.

The guide banks are generally provided in pairs, symmetrical in plan and may either be kept parallel or may diverge slightly upstream of the works. Symmetrical and parallel guide banks are usually adopted, unless, the local conditions warrant otherwise.

Before the water enters into the trough formed between these two guide banks, the flow may

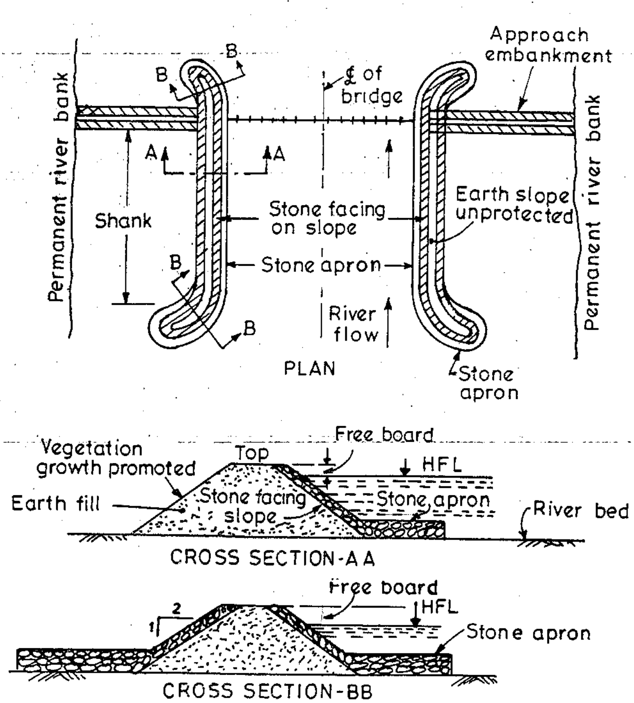


Fig. 8.13. Guide Bank details.

have to be partially controlled and directed with the help of marginal bunds or by groynes or both. The guide banks, usually, consist of two heavily built embankments in the river in the shape of a *bell mouth* (named after the name of its inventer – Mr. Bell). The portion of the river between the normal river banks and the guide banks is closed by ordinary embankments. Sometimes, one of the guide bank may become unnecessary and may be dispensed with, for economical reasons. This may happen either when the khadir bank is very near the works-site, thus serving the purpose of guide bank itself, or when the marginal bund is highly resistant to scouring, general layout of guide banks, plan, section, etc. are shown in Fig. 8.13.

Before we discuss the principles applied for designing the guide banks, it shall be worthwhile to speak something about the selection of the works-site.

Selection of works-site. It is evident that an engineering structure, such as a bridge, or a weir should be spanned in that portion of the river, where the distance between the khadir banks is minimum. This reduces the extent of possible embayment at the back of the guide banks (discussed at little later) and permits shorter guide banks. Further, on a meandering river, the river section at the bend is always wide and non-uniform ; deep on the concave bank and shallow on the convex. While the transition reaches connecting two adjacent bends are narrower and uniform in depth. *Bridges should therefore, preferably be built in these transition reaches, rather than on the bends.*

Further, in case of bridges, the river bed at the proposed bridge site should consist of deep strata of erodible land, so that after constriction, the river may be able to deepen the bed to gain an adequate waterway. If the bed consists of stiff clay etc., the constriction can be done only after due allowance is made for afflux, which may make it constlier.

In case of weirs and barrages, the usual practice is to construct the weir or the barrage, outside the main river channel in a minor creek which is dry in winter, and then to divert the main river channel through it. At the weir site, the river width is constricted. The meandering river upstream has, therefore, to be trained to flow between the two abutments of the weir, without causing any damage.

Principles and Factors Governing the Design of Guide Banks

(*i*) **Top level of guide banks.** The top level of guide banks is governed by HFL, afflux, velocity head, and freeboard. It can be obtained by adding all these four values.

Afflux

By afflux, we mean the rise in the high flood level of the river, upstream of the weir (or the bridge in case of non-erodible soils), or barrage, as a result of its construction. This rise in water level is maximum just near the site of constriction and reduces as we go away from it, upstream. The afflux, extends for a long distance on the upstream side, as shown in Fig. 8.14.

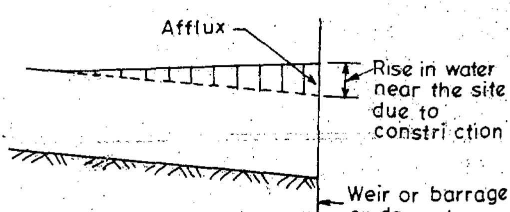


Fig. 8.14. Afflux formation at constriction.

The amount of afflux, in case of weirs or barrages founded on alluvial soils, is generally limited to 1 to 1.2 m, or more commonly as 1.0 m. In steep reaches of the river with boulder or rocky bed and in flashy rivers, a higher value of afflux has to be taken. The bed erosion and afflux are interlinked. *In case, a bridge is founded on a river. in which full bed scour develops before high floods, a negligible value of afflux may be taken.* While in boulder beds and flashy rivers, the time for bed scour may not be adequate, causing very high afflux. The amount of afflux governs the top levels of the guide banks as well as that of the marginal bunds*. The distance to which the afflux appreciably extends on the upstream side, governs the length and sections of the marginal bunds.

The Waterway and the Discharge per metre run

The waterway is the actual width from which the water has to flow after the river is constricted. Since this width is reduced at the works-site, the depth of water, and hence, the HFL will go up. The rise in this HFL is nothing but afflux. The limit placed on afflux automatically places a limit on the constriction or on the waterway, since the two are interdependent. In addition to high afflux, the insufficient waterway will cause excessive velocities, causing dangerously deep scour along the guide banks at the bridge piers, etc. On the other hand, too long a bridg weir may cause slack velocities, causing formation of shoals with consequent non-uniform flow distribution and an oblique flow.

A likely figure to be adopted for waterway may be given by Lecey's Regime perimeter (P), given by $P = 4.75\sqrt{Q}$; (because in larger rivers, width is approximately equal to its perimeter). In case of a bridge, obstruction caused by piers should be accounted for, and the above equation should be taken to represent the clear effective waterway. It should be remembered that the regime conditions are disturbed after the construction of the weir, and the above formula is not strictly applicable. Most of the existing weirs and bridges have been provided with a clear waterway from 10% to 50% more than that given by Lacey's Regime perimeter.

(*ii*) **Shape of guide banks in plan.** As stated earlier, the guide banks are generally provided in pairs, symmetrical in plan and may either be kept parallel or may diverge slightly upstream of the works. The diverging guide banks may be favoured on the ground that they cover larger width of the khadirs and exert an attracting influence on the flow. But they are not recommended mainly because for equal bank lengths, they provide relatively less protection to the approach embankment, under the worst possible embayment, as shown in Fig. 8.15.

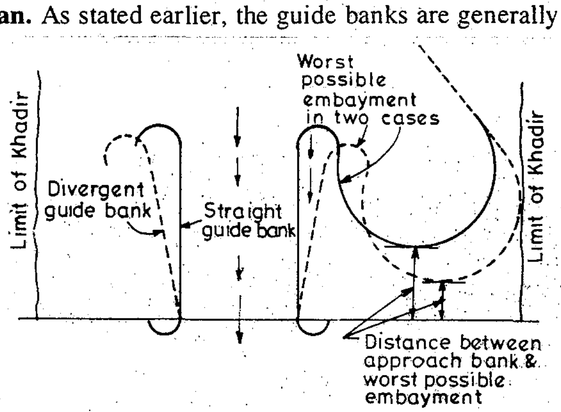


Fig. 8.15. Extent of protection provided by the straight and divergent guide banks.

Moreover, the divergent banks induce oblique flow and tend to form shoals in the centre. However, *in a particular case, where the approaching flow is oblique, it may become necessary to provide divergent banks in order to keep the flow active in adjacent spans.* For example in Yamuna River Bridge in Delhi (opposite old fort), a splay of 10° was given in the left guide bank so as to improve the intensity of flow in the left spans.

* Please see chapter 11 on "Diversion Head Works".

Note. Divergent banks exercise attracting influence on the flow and hence, suitable for oblique flows but bringing the embayment nearer the approach bank and hence, not suitable in ordinary cases.

In a river which is likely to meander on both sides, it is absolutely essential to make the banks symmetrical in order to straighten the current under all possible conditions, and thus, to ensure uniform distribution of discharge and scour. Symmetrical and parallel guide banks are, hence, usually adopted, unless the local conditions warrant otherwise.

(*iii*) **Length of the guide banks.** Spring and Gales have corelated the length of the guide bank with the length of structure between the abutments (L). According to Spring, the length of the upstream part of the guide bank should be equal to 1.1 L or even longer if required to obviate the possibility of the river curving at the back and cutting into the approach bank. The length of the guide bank on the downstream side should be between 0.1 L to 0.2 L.

According to Gales, the upstream length of the guide bank is 1.25 L for flood discharges up to 20,000 cumecs, and 1.5 L for flood discharges more than 20,000 cumecs. The length of the guide bank on the downstream side should be taken equal to 0.25 L. A convergence of 1 in 20 in the former case and 1 in 40 in the letter case has also been suggested by him. His recommendations are based on the assumption that the structure is constructed well within the *khadirs* and is provided with two training bunds. Based on Gales recommendations, the general layout dimensions of guide banks, are shown in Fig. 8.16.

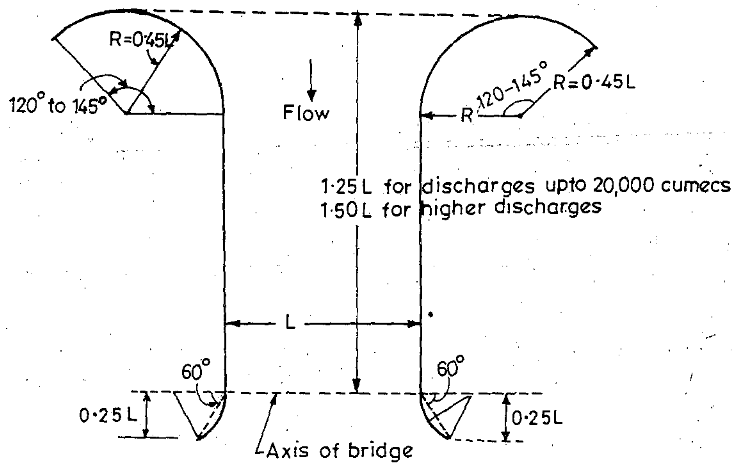


Fig. 8.16. Gale's recommendations for guide banks.

However, in certain cases, where the *khadir* is wide, the Gale's guide bunds may fail to provide enough protection to the approaching embankments. In such cases, the lengths of the guide banks and their layout should be such as to ensure the safety of the approach embankments against the worst possible embayment, in case the river embays considerably behind the training works. Only one loop is likely to be formed if the khadir bank is nearer, as shown in Fig. 8.17 ; and if the distance of the khadir edge is large, a double loop, as shown in Fig. 8.18 ; may be formed. Fig. 8.19 shows the anticipated double loop (dotted) and the actual developed loop on Gomti river u/s of Amghat road bridge.

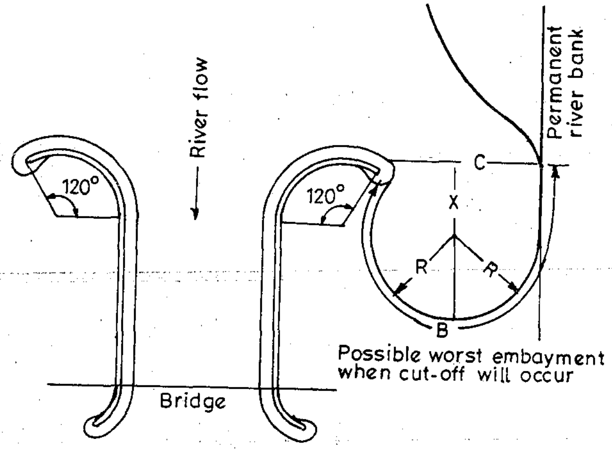


Fig. 8.17. Single loop formation.

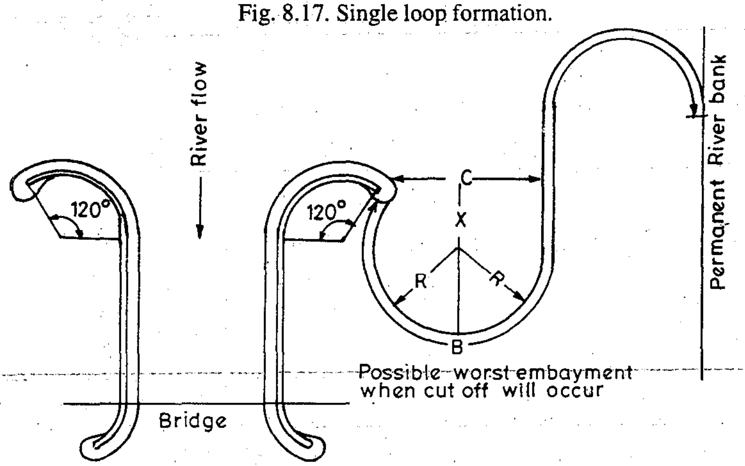


Fig. 8.18. Double loop formation.

Radius of the worst embayment. To determine the radius of the sharpest loop (*i.e.* minimum radius = r_{min}) the river course for the past several years is plotted and average values of M_L, M_B, B and C (where B and C are the arc and chord length) of the river are taken. The average value of the radius of the loop r_{av} may then be determined from the formula

$$\left(\frac{M_L}{4}\right)^2 = \frac{M_B - W}{2}\left[2r_{av} - \frac{M_B - W}{2}\right] \quad \text{...(8.3)}$$

where, M_L = Average meander length in metres

M_B = Average meander belt in metres

W = Average width of the river in the main channel during floods in the vicinity of the structure

r_{av} = Average radius of curvature.

The average value of radius of curvature obtained from the above equation is divided by a suitable constant so as to get the minimum radius of the worst loop. This constant has been found by model experiments to vary between 2.5 to 1.7 for discharges varying from 2000 to 90,000 cumecs, respectively. For acute meanders, B/C ratio is usually in the range of 2.0 to 2.2.

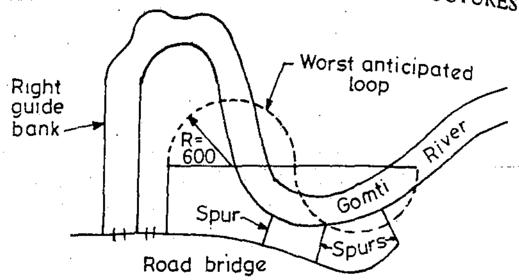


Fig. 8.19. Loops of Gomti River u/s of Amghat Road Bridge.

The length of the guide banks should, therefore, be fixed as per the above requirement and may, therefore, differ from those given by Spring or Gales. The lengths of guide banks should, therefore, be tested and modified by model studies.

(*iv*) **Radius of curved head of the guide banks**

(*a*) *Upstream curved portion.* The upstream curved portion of a guide bank is called 'the impregnable head'. The radius of curvature of the impregnable head should be sufficient enough, as not to cause intense eddies due to the curved flow near it. Greater the radius, flatter the curve, and lesser is the probability of formation of eddies. For a same river slope, coarser the bed material, shorter can be the radius, depending on the expected velocity. A safe value for the radius (R) may be taken equal to

$$R = 0.45\,L.$$

However, Spring suggested a value of R equal to 180 to 250 metres for rivers having velocities between 2.4 to 3.1 m/sec., respectively.

Gales, on the other hand, suggested a value of $R = 250$ metres for rivers having high flood discharge between 7,000 to 20,000 cumecs (with sharper curves permissible for discharges less than 7,000 cumecs); and a value of $R = 580$ metres for discharges varying from 40,000 to 70,000 cumecs. For intermediate discharges *i.e.* between 20,000 to 40,000 cumecs, the value of R may be obtained by interpolation.

The upstream curve is extended to subtend an angle of 120° to 140° at its centre, as shown in Fig. 8.20.

(*b*) *Downstream curved portion.* On the downstream, the river fans out so as to attain its normal width. The downstream portion of the guide bank ensures the safety of approach embankments and prevents the river from attacking them. This purpose can be well served *by providing short guide bund with sharp curved head.* A radius equal to half the radius at the upstream side, may be adopted here and sweep angle of 45° to 60° may be provided, as shown in Fig. 8.20.

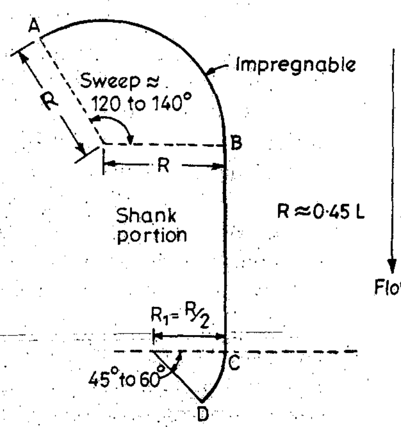


Fig. 8.20

(*v*) **The shank portion and section of bund.** The straight portion of the guide bank BC (Fig. 8.19) is called the shank portion. The guide banks should have a minimum top width of 4 metres so as to provide sufficient carriage-way. Extra width may, however, be provided for storing pitching materials, etc. Side slopes may vary from 1.5 *H* : 1 *V* to 2.5 *H* : 1 *V*, (but generally kept as 2 *H* : 1 *V*), depending on the construction materials and the height of the bund. A freeboard of 1.2 to 1.5 m is generally provided.

(*vi*) **Slope pitching.** The sloping water side of the entire guide bund as well as the sloping rear side of the curved portions are pitched with *one man stone* (*i.e.* a stone which can be lifted by one person—weighing 40 to 50 kg) or concrete blocks. The pitching should extend up to 1 m higher than HFL. The rear side of the shank portion is not pitched, but is generally coated with 0.3 to 0.6 m earth for encouraging vegetation growth, so as to make it resistant against rain, wind, etc. [Refer sections *AA* and *BB* in Figs. 8.22 (*a*) & (*b*)]

The thickness of the pitching on the river side may be calculated by the formula

$$t = 0.06\, Q^{1/3} \qquad \ldots(8.4)$$

where, t is the thickness of stone pitching in metres
Q is the discharge in cumecs.

The thickness of pitching should be 25% more at the impregnable head than for the rest of the bund.

(*vii*) **Launching apron.** Whenever, a sloping face is protected by stone pitching against scour, the pitching is extended beyond the toe on the bed in the form of packed stones, as shown in Fig. 8.21. This stone dumping is known as *Launching apron.*

If no such protection is provided, scour will occur at the toe with consequent under-mining and collapse of the stone pitching. In order to obviate such a danger to the slope, the pitching is extended on the horizontal river bed portion, which falls down into the scoured portion, as soon as the scour occurs.

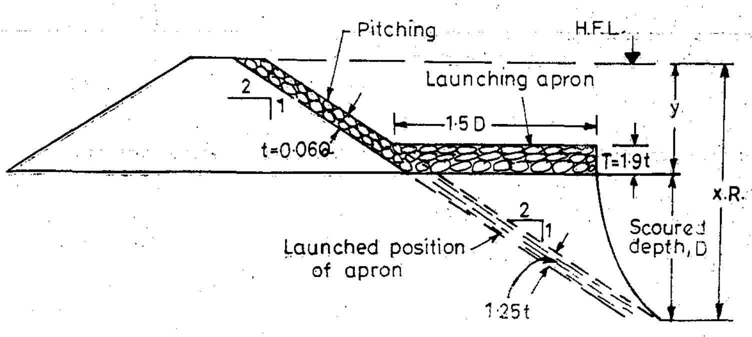


Fig. 8.21. Launching apron details.

The launching apron is generally laid in a width equal to 1.5 times the depth of scour (*D*) below the original bed. The total scour below HFL is taken as xR, where R is the Lacey's normal scoured depth given by equation

$$R = 0.47\left(\frac{Q}{f}\right)^{1/3} \qquad \ldots(8.5)$$

where Q is the discharge and f is the silt factor ;
and values of x are tabulated for different places, in Table 8.3.

Table 8.3

S. No.	*Location*	*Mean value of x*	*$D = xR$ – water depth above bed*
1	Noses of guide banks	2.25	$2.25R - y$
2	Transitions from noses to straight portions	1.50	$1.5R - y$
3	Straight reaches of guide bunds	1.25	$1.25R - y$

Generally, a scour slope of 2 : 1 is assumed and the thickness of the launched apron should be 1.25 t, where t is the thickness of stone pitching. Then the volume of stone required in the launched apron per unit length perpendicular to paper

$$= \sqrt{2^2 + 1^2} \cdot D \cdot (1.25\,t) = 1.25\,t \times \sqrt{5}\,D = \mathbf{2.8\,t\,.\,D.}$$

If the width of unlaunched apron is 1.5 D, then the thickness of the unlaunched (T) apron is given as :

$$T = \frac{2.8\,t..D}{1.5\,D} = 1.87\,t\text{ ; say } 1.9\,t.$$

Hence $\boxed{\mathbf{T = 1.9\,t}}$ ...(8.6)

where t is given by Eq. (8.4).

The width of the apron (1.5 D) will be different in different portions of guide bank, depending upon the values of D as per Table 8.3.

Example 8.1. *The following hydraulic data pertains to a bridge site of a river.*

Maximum discharge = 6,000 cumecs.

Highest flood level = 104.00 m.

River bed level = 100.00 m.

Average diameter of river bed material = 0.10 mm.

Design and sketch Bell's Bunds including the launching apron to train the river. Assume plentiful availability of boulders near the site.

Solution. The waterway between two guide bunds, planned as per Fig. 8.13 may be evaluated as follows :

The Lacey's regime waterway = clear waterway

$$P = 4.75\sqrt{Q} = 4.75\sqrt{6000}\text{ m} = 368\text{ m}.$$

Allowing 20% extra for piers, etc., the net spacing between the two guide bunds at the bridge site $= 1.2 \times 368 = 440$ m

Hence $L = 440$ m.

∴ The length of the guide bund upstream of bridge (From Fig. 8.16)
$= 1.25 \times 440 = 550$ m.

The length of the guide bund downstream of bridge

$$= 0.25\,L = 0.25 \times 440 = 110\text{ m}.$$

The radius of the curved head (upstream portion) may be kept

$$= 0.45\,L = 0.45 \times 440 = \text{say } 194\text{ m}.$$

The u/s end of guide bund may therefore, be curved by 130° (between 120 to 145°) with a radius of 194 m.

The d/s end of the guide bund may, therefore, be curved in such a way as to make an angle of 60°, as shown in Fig. 8.22 (*a*).

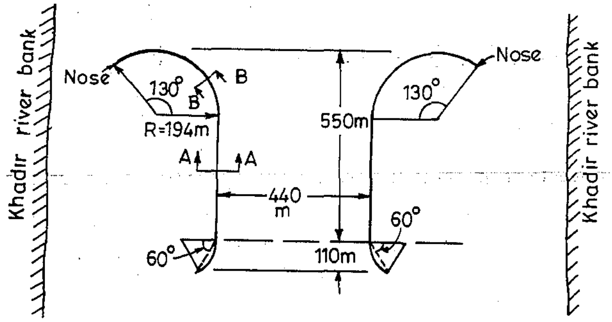


Fig. 8.22 (*a*) Plan of guide bunds for Example 8.1.

Cross-sections of the guide bunds

The given HFL at bridge site = 104.00 m.

Assuming a free-board of 1.5 m, and nil value of afflux, and ignoring velocity head*, we have the

Top level of guide bund = 104.00 + 1.5 = 105.5.

To be more safe and making an allowance for future settlement etc. ; let us adopt the top level of bund as 106.00 m.

Now, height of the bund above river bed level

= 106.00 − 100.00 = 6.00 m.

Assuming the top width of the bund as 5 m, and side slopes as 2 : 1, we have the required sections of the bund as shown in Figs. 8.22 (*b* & *c*).

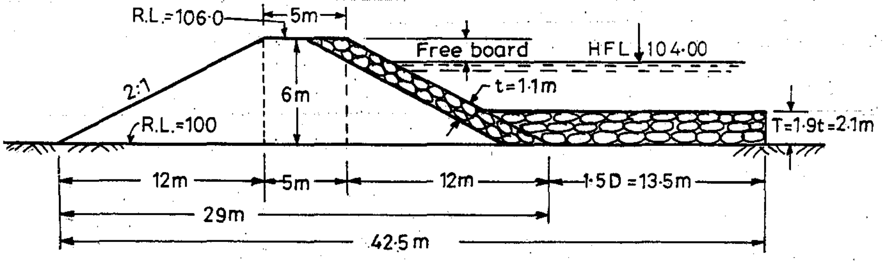


Fig. 8.22 (*b*) Cross-section (*AA*) of the straight reach of Bell's Bund.

The stone pitching and an apron must be provided on the slope on water side for the entire length of the bund ; however, the rear side will also be pitched for curved portions of the bund.

---

*Vel. head $= \frac{V^2}{2g}$

where , $V = \frac{6000}{PR} = \frac{6000}{368 \times 10.36} = 1.57$ m/.sec.

(*R* is calculated afterwards)

$\therefore$ Vel. head $= \frac{(1.57)^2}{2 \times 9.81} = 0.13$ m.

Design of stone pitching and apron

The thickness of stone pitching on the side (t) is given by Eq. (8.4), as :

$$t = 0.06\, Q^{1/2} = 0.06 \times (6000)^{1/2}$$
$$= 0.06 \times 18.2 = 1.09 \text{ m} ; \text{ say } 1.1 \text{ m}$$

The thickness of apron is given by eqn. (8.6)

$$= 1.9\, t = 1.9 \times 1.1 = 2.09 \text{ m} ; \textbf{ say 2.1 m.}$$

The length of the apron is given by 1.5 D, where D for *the straight reaches* of the guide bund is given as :

$$D = 1.25\, R - y$$

$$\text{where } R = 0.47 \left(\frac{Q}{f}\right)^{1/3} \quad ...(8.6)$$

where f is the Lacey/s silt factor given by Eqn. (4.24) as, $f = 1.76 \sqrt{d_{mm}}$

where, d_{mm} is the av. particle dia in mm = 0.1 mm (given)

$$f = 1.76 \sqrt{0.10} = 1.76 \times 0.322 = \mathbf{0.556.}$$

$$\therefore\ R = 0.47 \left(\frac{6000}{0.556}\right)^{1/3} = 0.47\,(10780)^{1/3}$$
$$= 0.47 \times 22 = \mathbf{10.36\ m.}$$

y = Depth of water above river bed level

$$= 104.0 - 100.00 = \mathbf{4.00\ m.}$$

$$\therefore \quad D = 1.25 \times 10.36 - 4.00 = 13 - 4.0 = \mathbf{9.0\ m.}$$

Length of apron = 1.5 D = 1.5 × 9.0 = 13.5 m.

For the curvilinear transition portions of the guide bund, however, D is given by

$$D = 1.5\, R - y = 1.5 \times 10.36 - 4.00 = 15.54 - 4.00 = 11.54; \text{ say } 12 \text{ m.}$$

Hence, the length of apron in the curved portions will be = 1.5 × 12 m = 18 m. Pitching and apron in these curved portions shall be provided on both sides, as shown in Fig. 8.22 (c).

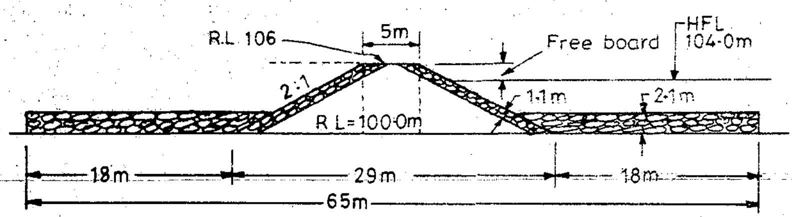


Fig. 8.22 (c) Cross-section (BB) of the curved portions of the Bell's bund.

The length of apron at noses should be increased to 1.5 D (where $D = 2.24 \times 10.36 - 4.00 = 19.36$) *i.e.* say 30 m.

(3) **Spurs of Groynes.** Groynes are the embankment type structures, constructed transverse to the river flow, extending from the bank into the river. That is why, they

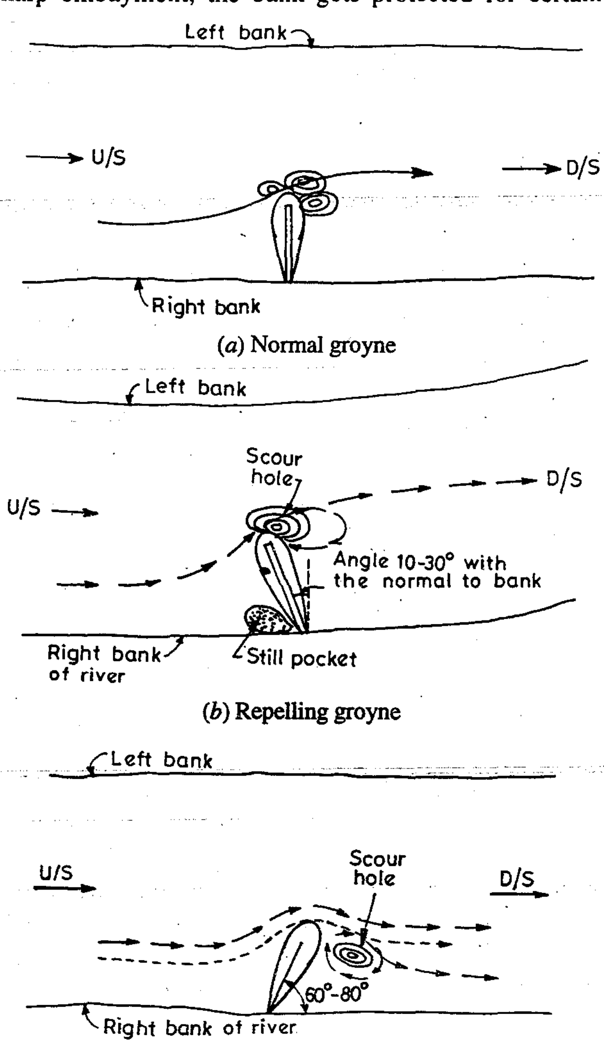
may also be called 'Transverse Dykes'. They are constructed, in order to protect the bank from which they are extended, by deflecting the current away from the bank. As the water is unable to take a sharp embayment, the bank gets protected for certain distance upstream and downstream of the groyne. However, the nose of the groyne is subjected to tremendous action of water, and has to be heavily protected by pitching, etc. The action of eddies reduces from the head towards the bank, and, therefore, the thickness of slope pitching and apron can be reduced accordingly.

Types of alignment. The groynes may be built either perpendicular to the bank line or they may be inclined upstream or downstream, as shown in Fig. 8.23.

A groyne aligned perpendicular to the bank line [Fig. 8.23(*a*)] is known as an **ordinary groyne** or a **normal groyne.**

A groyne pointing upstream [Fig. 8.23 (*b*)] has the property of *repelling* the flow away from it, and scour holes caused by the formation of vertical eddies are developed away from the bank, and near the head of the groyne. Such groynes, are called **repelling groynes.**

On the other hand, a groyne pointing downstream [Fig. 8.23 (*c*)], has the property of attracting the flow towards it, and is called an **attracting groyne.**



(*a*) Normal groyne

(*b*) Repelling groyne

(*c*) Attracting groyne

Fig. 8.23

In an attracting groyne, scour holes are developed nearer the bank, as compared to those in a repelling groyne. Since such attracting groynes bring the water current as well as scour holes nearer the bank and make it more susceptible to damage, they are generally not used.

The groynes are, therefore, generally aligned either perpendicular to the bank or *pointing upstream*. The 'perpendicular alignment' is generally used on convex banks, and the 'upstream pointing alignment' is generally used on concave banks.

When the length of an upstream pointing groyne is small, such that it changes only the direction of flow, without repelling it, it is called a **deflecting groyne**, instead of calling it a *repelling groyne.*

The repelling groynes are generally found to serve the desired results, provided they are properly located with due regard to their positioning in relation to the meander length. *It is desirable to test their performance in hydraulic models before constructing them in actual field.* These model studies in India are undertaken by Central Water and Power Research Station (CWPRS), Poona. *The angle of deflection upstream is generally kept at about 10 to 30° with a line normal to the bank.*

On the upstream side of a repelling groyne, a still water pocket is formed, where the suspended sediment carried by the river, gets deposited. The head of such a groyne, however, causes severe disturbance in the flow at its nose, where heavy scour takes place. Due to this heavy attack of swirling river current at the head, a repelling groyne needs heavy protection at and near its head, in the form of heavy stone pitching and apron, laid by placing stones filled in wire crates in and around the earthen groyne.

Groynes may be constructed either singly or in series, depending upon the need. When constructed in series, they are more effective, as they create a pool of almost still water between them, which resists the current and gradually accumulates silt between them, thus forming almost a permanent bank after certain time. The choice of using them in series arises, if the reach to be protected is long, or if a single groyne is neither strong enough to deflect the current nor quite effective for silt deposition upstream and downstream of itself.

Length of the groynes. The lengths of the groynes depend upon the position of the existing bank line and the designed or expected bank line for trained river. Too long groynes on easily erodible rivers, are susceptible to damage and failure. In such cases, the best results can be obtained by starting with a shorter length and to extend the groyne gradually, as silting between them proceeds. However, no general rule can be formulated for fixing the length of the groynes. It depends mainly upon the exigencies arising in a specific case. For example, if the entire river course is required to be changed by repelling it towards the opposite bank by means of a single groyne, the groyne must, necessarily be, sufficiently long. Erosion of the opposite bank caused by this shift of water, should be anticipated and allowed for, whenever necessary.

Spacing of the groynes. As each groyne can protect a certain length, the primary factor governing the spacing between two adjacent groynes, is their length. The spacing is, therefore, taken as a certain proportion of their length. Apart from the length, the spacing may be governed by the following factors :

(*a*) *Type of bank where the groyne is to be located.* Larger spacing is required for locating groynes on convex banks, and a smaller one for concave banks with intermediate values at the crossings. A spacing of 2 to 2.5 times the length of the groyne is generally adopted at convex banks, while a spacing equal to the length of the groyne is mostly adopted for concave banks.

(*b*) *The width of the river.* For rivers of equal flood discharges, a larger spacing is preferred for wider rivers than for narrower rivers.

(*c*) *Type of groyne.* A higher value of spacing may be used for permeable groynes as compared to that required for impermeable groynes.

Types of groynes. Based upon their material of construction, the groynes may be divided into two types, namely :

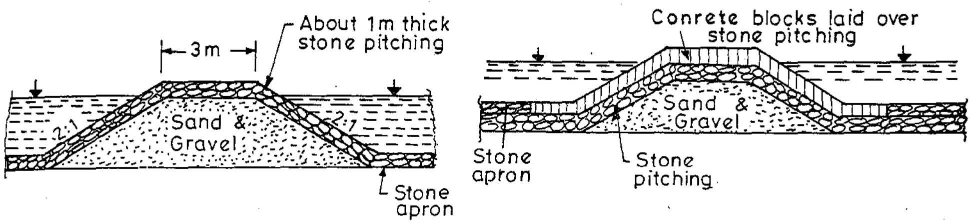
(*i*) *Impermeable groynes* ; and

(*ii*) *Permeable groynes.*

(*i*) **Impermeable groynes**. Impermeable groynes are also called as solid groynes or embankment groynes. These groynes may be rockfill embankments or earthern embankments, armoured with stone pitching, concrete blocks, etc. The head of the groyne needs special protection and is generally provided with a launching apron in addition to the increased pitching, as shown in Fig. 8.24 (*b*). These groynes are called 'impermeable groynes' because they do not allow any significant flow through them.

Their design is the same as that for the guide bund with an apron. Commonly adopted dimensions of the groyne embankment are :

Freeboard = 1 m
Top width = 3 m
Side slopes = 2 : 1
Head = square and having a slope of 5 : 1
Apron = as per standard design requirements.



(*a*) Normal section (*b*) Section at the nose (*i.e.* the head)

Fig. 8.24. Impermeable groyne-section.

(*ii*) **Permeable groynes.** Permeable groynes do permit restricted flow through them. The groynes are more or less temporary structures and are susceptible to damage by floating debris, etc. The common materials used as permeable groynes, are :

(*a*) Trees used as groynes, called *Tree Spurs.*

(*b*) Timber stakes or wooden piles called *Balli Spurs.*

(*c*) Stone filled in balli crates.

(*d*) Stone filled in wire crates.

Permeable groynes, simply obstruct the flow, reducing its velocity and causing silt deposition. *They are, therefore, best suited for rivers carrying huge sediment load in suspension.* In comparatively clear rivers, they reduce the erosive strength of the current, and thus, prevent local bank erosion. Permeable spurs do not change the flow abruptly as is done by impermeable spurs, and hence, intense and serious eddies and scour holes are not developed. They are cheaper and perhaps the best for silt laiden rivers. When the groyne is to be submerged, then permeable groynes give much better results, because they do not generate so strong turbulence as is generated by submerged—impermeable groynes, making them susceptible to be washed away due to over-topping.

Balli spurs are being successfully used these days on many rivers in plains, and are becoming very popular.

In such spurs, sal ballis are driven vertically into the river bed, projecting from the bank to be protected, towards the interior of the river, at suitable spacings of about 1 m or so in two rows in zig-zag fashion. The top level of the ballis is kept at about 15 cm above the dry weather flow level of the river. The ballis are connected at top by cross ballis and longitudinally by longitudinal ballis, as shown in Fig. 8.25.

The length of the spur which projects into the river is kept at about 15 to 20 m or so, and the spacing between the spurs is kept at about 50 m or so. The length and spacings are interdependent on each other. Stone is dumped into the bottom round the spur as shown. The depth of the stone is kept at about 0.8 m or so. The stone so dumped will surround the ballis and prevent scouring and their consequent removal.

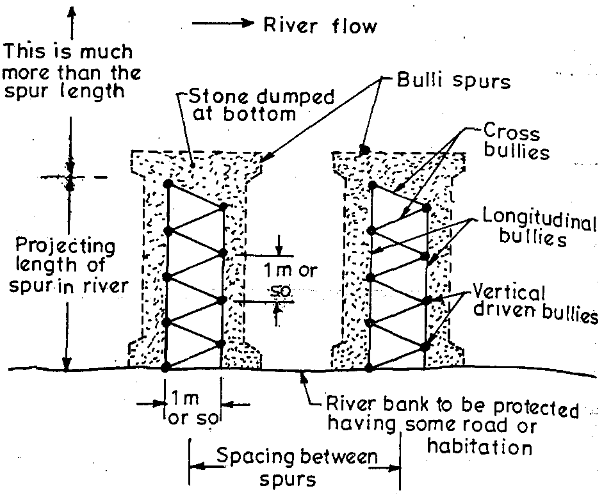


Fig. 8.25. Plan view of Balli spurs constructed in a river.

The balli spurs so constructed along the river bank, promote silting near this bank; thereby avoiding any erosion of the bank which might have taken place in their absence, endangering the existing roads or establishments in the vicinity of this bank.

Balli spurs constructed on Yamuna river in Delhi at Barapula near Ring road and at Khijrabad village, under the supervision of this author, had proved very successful, leading to enough silting and protecting the bank reach from future erosion. However, their effect was felt downstream, where erosion did take place at Jogabai village.

Although such permeable spurs are excellent tools for training heavily silted rivers, yet their biggest drawback is their short life. They are not strong enough, as to resist shocks and pressure from debris, floating ice and logs of wood, etc. These are, therefore, not suitable for upper reaches of rivers. Moreover during floods, submerged groynes are a danger to navigation.

T-shaped groynes. Denehey's T-shaped groyne is a special type of groyne developed in India. It is an ordinary groyne provided with an extra cross groyne at the

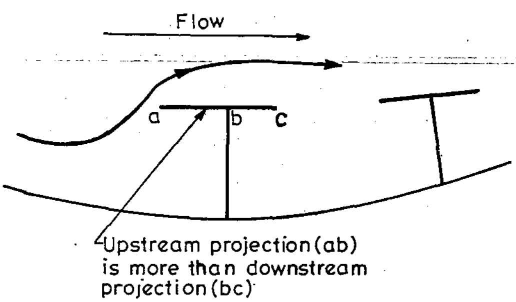


Fig. 8.26. T-shaped groyne

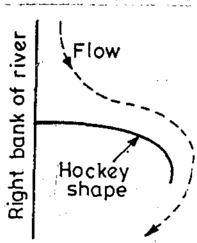


Fig. 8.27. Hockey shaped groyne.

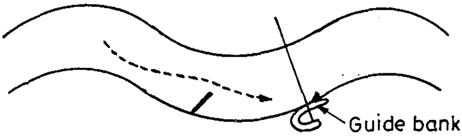
head giving it a T-shape. The cross groyne protects the main groyne on the same principles as the main groyne saves the bank. The longer arm (*ab*) of the T is provided on the upstream, and the shorter one (*bc*), on the downstream, as shown in Fig. 8.26.

These groynes are usually spaced at about 800 metres apart.

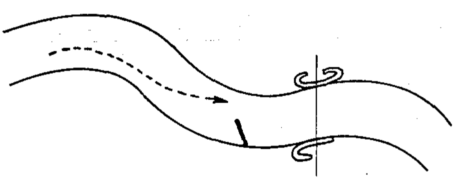
Hockey-shaped groynes. These groynes are shaped like a hockey stick at their lower end, as shown in Fig. 8.27.

These groynes exert an 'attracting' type of influence on the flow and hence are not useful for bank protection for repelling the current away from it.

Concluding remarks on groynes. In the end, it may be repeated that the groynes should be constructed after model studies. Their design is not much amenable to theoretical investigation and has to be checked and tested with model studies. Whereas, a series of groynes may be useful for general deflection of the river, a single groyne placed suitably may best serve the purpose of controlling a river at a certain works-site, such as shown in Fig. 8.28. (*a*) and (*b*).



Water attracted towards guide bank, protecting the free bank
(*a*) attracting groyne



Water deflected away from concave side reducing meander tendencies
(*b*) deflecting groyne

Fig. 8.28

(4) **Artificial cut-offs.** It was discussed earlier, that a considerably meandering river may attain its original straight flow by means of a cut-off. A cut-off channel may develop by itself or may be induced artificially. When a meander goes on increasing and may endanger some valuable land or property, then the river course may be straightened by inducing an artificial cut-off. The newly developed course will be far away from the establishments which otherwise would have been affected. For inducing an artificial cut-off, only a pilot channel is required to be excavated in case of rivers having easily erodible beds. The flood water will gradually enlarge **the pilot cut** to the required cross-section and will abandon the old curved channel, provided, the circumstances for the development of this cut-off are favourable.

It has been established that the side pilot channel will be self scouring, provided $\left(\frac{R}{L^2}\right)$ *is greater for the cut than for the original course* (where R is the hydraulic mean depth $\left(R=\frac{A}{P}\right)$ and L is the length along the cut or along the river course as the case may be. Hence, a deeper and more hydraulically efficient channel $\left(\text{such that } \frac{R}{L^2} \text{ is greater for the cut than for the main course}\right)$ is required to be excavated for inducing a cut-off. *The pilot cut should be made as deep as possible.* As tractive force is directly proportional to depth, a deeper cut would be helpful for rapid development. The width of the cut is relatively less important and is governed by the minimum working space required for the excavating machines, etc.

Moreover, the alignment of the cut should be tangential to the main direction of flow approaching and leaving *the cut.*

It was discussed earlier that a cut-off brings violent changes in the river regime. To keep this violence within permissible limits, a full scale diversion of the river through an artificial cut-off is seldom accomplished at any one time. The complete formation of a cut-off is generally brought about slowly and slowly. The common practice is to make pilot cuts which carry 8 to 10 per cent of discharge in the beginning, and are developed subsequently to carry about 40 to 50 per cent of the total river discharge.

Since a cut-off helps in reducing flood heights and flood periods, it helps in shortening the navigation course and also helps in protecting endangered establishments. It is, thus, a useful river training measure. However, cut-offs as river training measure are not enough by themselves. Although they correct the instability and inefficiency at sharp bends, they do little to correct conditions in the reaches between these bends. For this reason, extensive supplementary training works are required between the cut-offs. The main purpose of these supplementary training works is the creation of a uniform river width and establishment of a central river channel deep enough to maintain itself by normal scour action. Construction of groynes and revetments at places, which are susceptible to erosion, are the common supplementary training works.

(5) **Pitching of banks and provision of launching aprons.** Protection of banks is a part and parcel of river training works. Sometimes 'Bank protection' is separated from the 'River Training' under the argument that the former has a limited function of protecting the bank, while the latter aims at training the river to a desired stable course. However, since bank protection itself helps in training the river, the two are generally treated as one and the same thing.

Banks of a river are directly protected by stone pitching, or by concrete blocks, or by brick lining or by growing vegetative cover, etc. Concrete blocks are very costly, and stone pitching is mostly adopted, if available without much difficulty. The banks of the river are made stable by giving them a stable slope varying from 1 : 1 to 2 : 1 depending upon the material of the bank. They are then pitched, so as to make them strong enough to resist erosion.

Sometimes, as discussed earlier, a launching apron is projected from the toe of the bank into the river, so as to prevent scour at the toe and the consequent fall of slope pitching. The standard design of an apron has already been discussed and is based on the principle that the stone in the apron has to launch into the deepest scour (D) possible at the location, to a slope of 2 : 1, at an average thickness of 1.25 times the thickness of pitching provided at the bank. The deepest scour may be taken equal to x times the Lacey's Regime scoured depth ; x generally varying from 1 to 2.5 or 3 for different places.

(6) **Pitched islands.** A 'pitched island' is an artificially constructed island in the river bed and is protected by stone pitching on all sides. Because of the turbulence generated by the island in its vicinity, the river channel around the island gets deepened and thus, attracting the river towards itself and holding it permanently. Pitched islands may therefore, help in attracting the current towards themselves and thus, reduce undue concentration on the opposite banks.

The device of pitched island as a river training measure is of a recent origin and is still in the experimental stages. Nevertheless, *experience* has proved that pitched island is a very effective means of controlling and training rivers, especially in the vicinity of control points, such as a bridge or a weir or a barrage, etc. However, model studies must be conducted before adopting pitched island, as a river training measure.

(7) **Miscellaneous methods.** (*i*) *Submerged Dikes* (called Sills) are used as a river training measure in particular situations. Sometimes, a river may create deep channels in the vicinity of certain pucca structures and are required to be corrected. In such situations, **sills** are placed across the scoured portion of the bed, with their top levels at or slightly below the designed bed level aspired to be achieved after correcting the deep scours. They are spaced closely, so as to ensure their proper functioning.

(*ii*) *Closing Dykes* are sometimes used to close a particular flow, so that the river flow may be directed in some other desired direction.

Conclusions and remarks. River training works depend mainly upon the type of the river, its regime and upon the characteristics of its flow. *There are no two countries with the same hydrology ; in the same country, there are no two rivers with the same regime ; and even in the same river, there are no two floods of the same characteristics. River training works, therefore, vary from place to place and from time to time and also depend upon the finances available at a particular time.* A particular method of river training, which has been successful in a particular reach on a particular river, may not be the best solution for the other rivers or for other reaches of the same river.

Hence, no particular method of river control can be stated to be the best. It all depends upon the exigencies arising out of a particular problem. However, in general, it can be stated that no river training method is of immense use in isolation, unless it is supplemented by other measures. A comprehensive planning and model testing is necessary before any measures are undertaken to control and train the river. If roughly planned, costly structures may either be washed away in a few days or may create worse or irreversible consequences causing tremendous losses and devastations.

PROBLEMS

1. Comment on the statement—"Rivers have played an important part in the development of civilisation right from the early ages."

2. (*a*) What is meant by "meandering of rivers" and what are its causes ? How does the increasing river length due to meandering is counteracted in nature ?

(*b*) Write short notes on the following river training works :

(*i*) Levees (*ii*) Guide banks (*iii*) Repelling groynes (*iv*) Cut-off

3. Give a typical plan and section of Bell's bund, and explain its design procedure step by step.

Differentiate between 'attracting' and 'repelling' spurs explaining their action in river training.

4. What are 'cut-offs' ? How are they used as a method of river training ?

Draw a neat plan and section of a Bells Bund and give salient steps of its design procedure.

5. (*a*) What are the different types of rivers and their characteristics ?

(*b*) Name the important Himalayan Indian rivers, and compare their behaviours with the other Non-Himalyan Indian rivers.

(*c*) Name the important types of river training methods indicating the purpose for which each type is adopted.

6. Explain how do the following assist in river control :

(*i*) Spurs (*ii*) Revetment (*iii*) Guide bunds.

Draw a neat plan and section of an earthen Tee-spur showing protective apron.

State the good and evil effects of embankment construction for flood control.

7. What is the difference between permeable and impermeable spurs ? Describe briefly the type of spurs commonly used in river control.

Data given below refer to a Bell's bund :

High flood level	206.00 m.
Low water bed level	202.00 m.
Maximum scour depth (Lacey's formula) R (with factor or safety)	9.5 m.
Free-board	1.5 m.
Side slope of embankment	2 : 1
Thickness of stone apron when launched	40 cm.

Determine volume of stone required per metre length of shank. (Assume 25% loss). Draw a neat sectional view of the bund with necessary dimensions.

8. (*a*) What is meant by 'river training' and what are the different objectives served by it.

(*b*) Enumerate the different methods which are used for controlling and training rivers, and describe any one of these methods in details. Also discuss the circumstances under which a particular method of river training is to be adopted.

9. (*a*) Explain with neat sketches the different types of 'spurs' which are commonly used for controlling and training Indian rivers ?

(*b*) Discuss briefly the usefulness of the 'Balli spurs' on North Indian rivers.

(*c*) What are 'cut-offs' and how are they artificially induced ? What are their advantages and disadvantages ?

10. Write short notes on any three of the following :

(*i*) Importance of rivers and necessity of controlling them.

(*ii*) Aggrading and degrading rivers.

(*iii*) Meandering of rivers and meander parameters.

(*iv*) Cut-offs and cut-offs ratio.

(*v*) High water, low water, and mean water training.

(*vi*) Pitching of Bank's and Pitched island's as the means of training rivers.

(*vii*) Groynes, their types and uses.

(*viii*) Use of Levees for protecting cities from floods.