embankments.

(2) **Zoned Embankment Type.** Zoned embankments are usually provided with a central impervious core, covered by a comparatively pervious transition zone, which is finally surrounded by a much more pervious outer zone (Fig. 20.2).

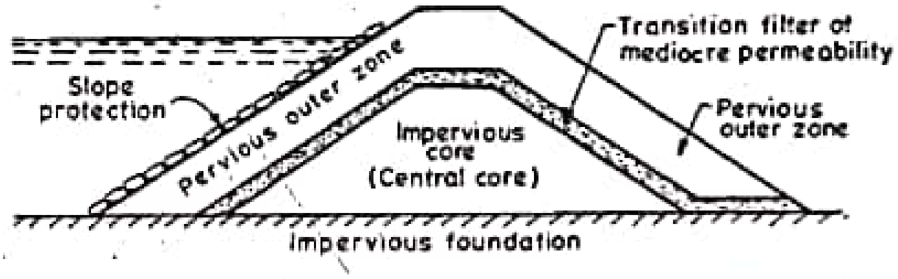


Fig. 20.2. Zoned type embankment.

The central core checks the seepage. The transition zone prevents piping through cracks which may develop in the core. The outer zone gives stability to the central impervious fill and also distribute the load over a large area of foundations.

This type of embankments are widely constructed and the materials of the zones are selected depending upon their availabilities. *Clay, inspite of it being highly impervious, may not make the best core, if it shrinks and swells too much. Due to this reason, clay is sometimes mixed with fine sand or fine gravel, so as to use it as the most suitable material for the central impervious core. Silts or silty clays may be used as the satisfactory central core materials. Freely draining materials, such as coarse sands and gravels, are used in the outer shell.* Transition filters are provided between the inner zone and the outer zone, as shown in Fig. 20.2. This type of transition filters are always provided, whenever there is an abrupt change of permeability from one zone to the other.

(3) **Diaphragm Type Embankments.** Diaphragm type embankments have a thin impervious core, which is surrounded by earth or rock fill. The impervious core, called diaphragm, is made of impervious soils, concrete, steel, timber or any other material. It acts as a water barrier to prevent seepage through the dam. The diaphragm may be placed either at the centre as a central vertical core or at the upstream face as a blanket. The diaphragm must also be tied to the bed rock or to a very impervious foundation material, if excessive under-seepage through the existing previous foundations has to be avoided (Fig. 20.3).

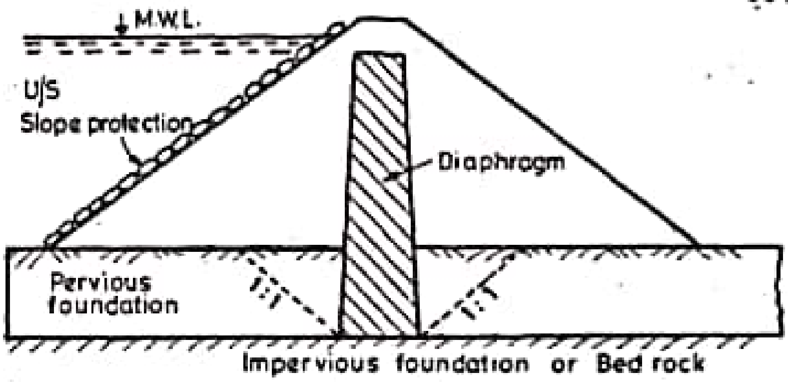


Fig. 20.3. Diaphragm type embankment.

The diaphragm type of embankments are differentiated from zoned embankments, depending upon the thickness of the core. If the thickness of the diaphragm at any elevation is less than 10 metres or less than the height of the embankment above the corresponding elevation, the dam embankment is considered to be of 'Diaphragm Type'. But if the thickness equals or exceeds these limits, it is considered to be of zoned embankment type.

20.3. Methods of Construction

20.1. Introduction

Earthen dams and earthen levees are the most ancient type of embankments, as they can be built with the natural materials with a minimum of processing and primitive equipment. But in ancient days, the cost of carriage and dumping of the dam materials was quite high. However, the modern developments in earth moving equipments have considerably reduced the cost of carriage and laying of the dam materials. The cost of gravity dams on the other hand, has gone up because of an increase in the cost of concrete, masonry, etc. Earthen dams are still cheaper as they can utilise the locally available materials, and less skilled labour is required for them.

Gravity dams and arch dams require sound rock foundations, but earthen dams can be easily constructed on earth foundations. However, earth dams are more susceptible to failure as compared to rigid gravity dams or arch dams. Before the development of the subject of Soil-Mechanics, these dams were being designed and constructed on the basis of experience, as no rational basis for their design was available. This led to the failure of various such earthen embankments. However, in these days, these dams can be designed with a fair degree of theoretical accuracy, provided the properties of the soil placed in the dam, are properly controlled. This condition makes the design and construction of such dams, thoroughly interdependent. Continuous field observations of deformations and pore water pressures have to be made during the construction of such dams. Suitable modifications in the design, are then made during construction, depending upon these field observations.

20.2. Types of Earthen Dams

The earthen dam can be of the following three types :

1. *Homogeneous Embankment type*
2. *Zoned Embankment type*
3. *Diaphragm type.*

These three types of dams are described below :

(1) Homogeneous Embankment Type. The simplest type of an earthen embankment consists of a single material and is homogeneous throughout. Sometimes, a blanket of relatively impervious material may be placed on the upstream face. A purely homogeneous section is used, when only one type of material is economically or locally available. Such a section is used

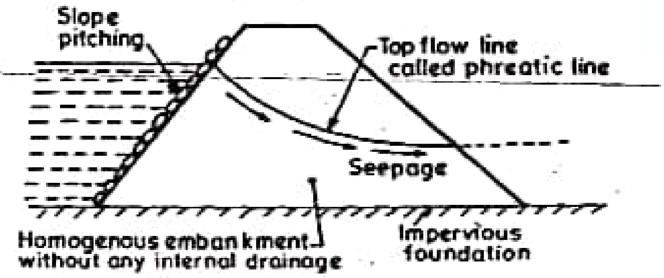


Fig. 20.1 (*a*). Homogeneous type embankment.

for low to moderately high dams and for levees. Large dams are seldom designed as homogeneous embankments.

A purely homogeneous section poses the problems of seepage, and huge sections are required to make it safe against piping, stability, etc. Due to this, a homogeneous section is generally added with an internal drainage system : such as a horizontal drainage filter [Fig. 20.1 (*b*)], rock toe, etc. The internal drainage system keeps the phreatic line (*i.e.* top seepage line) well within the body of the dam, and steeper slopes and thus, smaller sections can be used. the internal drainage is, therefore, always provided in almost all types of embankments.

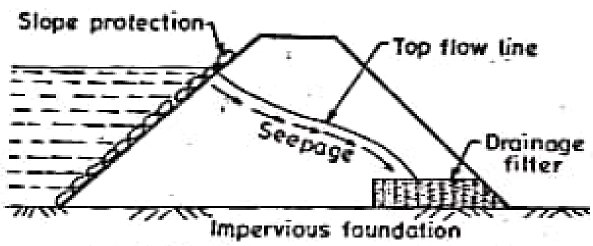


Fig. 20.1 (*b*). Homogeneous embankment provided with a drainage filter.

20.7. Causes of Failure of Earthen Dams

Earth dams are less rigid and hence more susceptible to failure. Every past failure of such a dam has contributed to an increase in the knowledge of the earth dam designers. Earthen dams may fail, like other engineering structures, due to improper designs, faulty constructions, lack of maintenance, etc. The various causes leading to the failure of earth dams can be grouped into the following three classes :

(1) Hydraulic failures

(2) Seepage failures

(3) Structural failures.

These causes are described below in details :

20.7.1. Hydraulic failures. About 40% of earth dam failures have been attributed to these causes. The failure under this category, may occur due to the following reasons:

(*a*) *By over topping.* The water may overtop the dam, if the design flood is under-estimated or if the spillway is of insufficient capacity or if the spillway gates are not properly operated. Sufficient freeboard should, therefore, be provided as an additional safety measure.

(*b*) *Erosion of upstream face.* The waves developed near the top water surface due to the winds, try to notch-out the soil from the upstream face and may even, sometimes, cause the slip of the upstream slope. Upstream stone pitching or riprap should, therefore, be provided to avoid such failures.

(*c*) *Cracking due to frost action.* Frost in the upper portion of the dam may cause heaving and cracking of the soil with dangerous seepage and consequent failure. An additional freeboard allowance upto a maximum of say 1.5 m should, therefore, be provided for dams in areas of low temperatures.

(*d*) *Erosion of downstream face by gully formation.* Heavy rains falling directly over the downstream face and the erosive action of the moving water, may lead to the formation of gullies on the downstream face, ultimately leading to the dam failure. This can be avoided by proper maintenance, filling the cuts from time to time especially

during rainy season, by grassing the slopes and by providing proper berms at suitable heights (Fig. 20.5), so that the water has not to flow for considerable distances. The proper drainage arrangements are made for the removal of the rain water collected on the horizontal berms. Since the provision of berms ensures the collection and removal of water before it acquires high downward velocities, the consequent erosion caused by the moving water (run off) is considerably reduced.

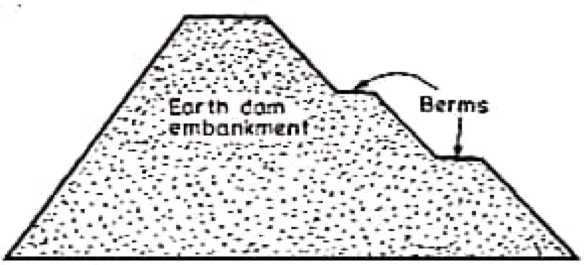


Fig. 20.5

(*e*) *Erosion of the d/s toe.* The d/s toe of the earth dam may get eroded due to two reasons, *i.e.* (*i*) the erosion due to cross currents that may come from the spillway buckets; and (*ii*) the erosion due to tail water. This erosion of the toe can be avoided by providing a downstream slope pitching or a riprap up to a height slightly above the normal tail water depth. Side walls of the spillway (called diaphragm walls) must be of sufficient height and length, as so to prevent the possibility of the cross flow towards the earthen embankment.

20.7.2. Seepage Failures. Controlled seepage or limited uniform seepage is inevitable in all earth dams, and ordinarily it does not produce any harm. However, uncontrolled or concentrated seepage through the dam body or through its foundation may lead to piping or sloughing and the subsequent failure of the dam. Piping is the progressive erosion and subsequent removal of the soil grains from within the body of the dam or the foundation of the dam. Sloughing is the progressive removal of soil from the wet downstream face. More than 1/3rd of the earth dams have failed because of these reasons.

$$\frac{D}{B} \times \Delta = 8.64 \Rightarrow \boxed{\Delta = \frac{8.64 \times B}{D}}$$

Given D = 780 hectates/ cumec

B = 140 days.

$$\therefore \quad \Delta = \frac{8.64 \times B}{D} = \frac{8.64 \times 140}{780} = 1.55 \text{ m.}$$

5. Write briefly the different types of dams based on their construction material.

Ans. Classification of Dam

Based on materials of contruction

Rigid Dam – It is constructed with rigid materials like masnory, concrete, steel or timber. It is designated as (a) Masonry dam (b) Concrete dam (c) Steel dam (d) Timber dam.

Non rigid Dam – It is constructed with non-rigid materials such as earth, clay, rock materials etc. It is designated as (a) Earthen Dam (b) Rock fill dam (c) composite dam.

Solid Gravity Dam – The solid gravity dam may be constructed with rubble masnory or concrete. The ruble masonry is done according to the shape of the dam with rich cement mortar. The u/s and d/s faces are finished with rich cement martar. Now-a-days, concrete gravity dams are prefered, because they can be easily constructed by laying concrete, layer by layer with construction joints. But good rocky foundation must be available to bear the enormous weight of the dam. The solid gravity dam resists all the forces acting on it by its self weight.

Earthen Dam – Earthen dams are constructed purely by earthwork in trapezoidal section. These are most economical and suitable for weak foundation. Earthen dams are classified as follows

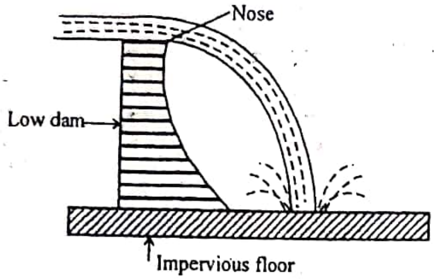
(i) Rolled fill dam (ii) Hydraulic dam. (iii) Semi hydraulic fill dam. (iv) Homogeneous type dam (v) Zoned type dam . (vi) Diaphragm type dam.

6. What is spillway ? Write briefly types and function of spillway.

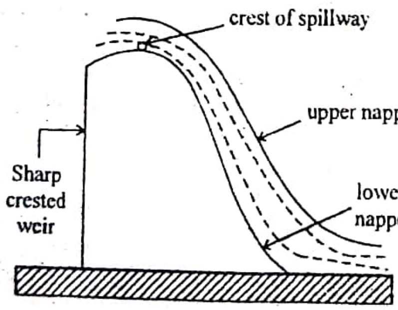
Ans. Spill way are openings provided at the body of the dam to discharge safely the excess water or flood water when the water level rises above the normal pool level.

Types of Spill Ways – The following are the common types of sipll ways

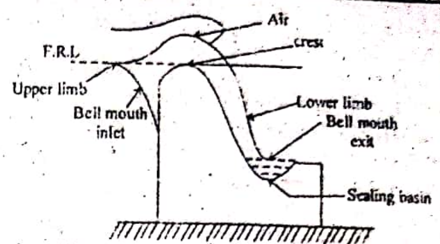
Drop Spill way – In drop spill way, the over flowing water falls freely and almost vertically on the d/s side of the hydraulic structure. This type of spill way is suitable for weirs or low dams. The crest of spill way is provided with nose so that the water jet may not strike the d/s base of the structure. To protect the structure from the effect of scouring horizontal imprevious apron should be provided on the downstream side.



Ogee Spillway – The ogee spill way is a modified form of drop spill way. Here the d/s profile of the spill way is made of coincide with the shape of the lower nappe of the free falling waterjet from a sharp crested weir. In this case, the shape of the lower nappe is similar to a profective and hence d/s surface of the ogee spill way will follow the parabolic path where 'D' is the origin of the parabola. The d/s face of the spill way forms a concave curve froma point 'T' and meets with the d/s floor.



Siphon Spill way – The spill way which acts on the principle of siphon is known as siphon spill way.



The spill ways are provided on the dam for the following reasons.

→ The ht. of the dam is always fixed according to the maximum reservoir capacity. The normal pool level indicates the maximum capacity of the reservoir. The water is never stored on the reservoir above this level. The dam may fail by over turning so, for the safety of the dam the spill ways are essential.

→ The top of the dam is generally utilised by making road. The surplus water is not be allowed to over top the dam. So to stop the over topping by the surplus water, the spill ways become extremely essential.

→ To protect the d/s base and floor of the dam from the effect of scouring and erosion, the spill ways are provided so that the excess water flows smoothly.

7.(b) Crop rotation

Ans. The process of changing the type of crop for the cultivation on the same land is known as crop rotation. It is found by experiment that if the principle of crop rotation is practised, the fertility of the soil can be restored.

(c) Perennial irrigation

Ans. In this system, a wier or a barrage is constructed across the perenial river to raise the water level on the up stream side or a dam is constructed to form a storage reservoir. Then main canal is constructed on either or both the banks of the river. Regulator is constructed at the head of the canal to control flow of water through the canal towards the agricultural land.

(d) Unconfined aquifer

Ans. It is the topmost aquifer in which the water table lies on the surface of saturation. So it is also known as water table aquifer. The surface water enters this aquifer through the surface soil.

(i) State two important reasons of failure of dam.

Ans. Important reasons of failure of dam are

→ Over-turning

→ Seepage failure

→ Structural failure

→ Under mining

→ Cracking

(j) In which conditions earth dam is constructed ?

Ans. Earthen dams are constructed purely by earthwork in trapezoidal section. These are most economical and suitable for weak foundation.

(l) Define cavity well.

Ans. In case of cavity well, the G.I. pipe of required diameter is driven into the ground up to the depth so that it just penetrates clay layer and finds a water bearing strata.

2.(a) Discuss briefly the factors on which duty

(b) Describe with neat sketch the functions of cross-regulator and head regulator.

Ans. The main functions of a head regulator are

i. To regulate or control the supplies entering the off-take channel.

ii. To control silt entry into the off-take channel.

iii. To serve as a meter for measuring discharge.

The main functions of a cross-regulator are

a. To effetively control the entire canal irrigation system

b. When the water level in the main channel is low, it helps in heading up water on the u/s and to feed the off-take channels to their full demand in rotation.

c. They help in absorbing fluctuations in various sections of the canal system and in preventing the possibilities of breaches in the tail reaches.

d. Cross regulator is often cmbined with a road bridge, so as to carry the road which may cross the irrigation channel near the site of the cross regulator. It is also usually combined with a fall (if required at the site of cross regulator) when it is called a fall- regulator.

5. (a) Describe briefly the various causes of failure of gravity dam.

Ans. The following forces act on a gravity dam:

(1) Weight of the dam - The weight of the dam is the main stabilising force which counter balances all the external forces acting on the dam. So the dam should be constructed with heavy materials of high specific gravity. For the construction of dam the specific weight of concrete and stone masonry should not be less than 2400kg/m³ and 2300kg/m³ respectively. The weight of the dam actsthrough its centre of gravity. For design purpose, the weight per unit length should be calculated. The c.g of the dam is calculated with respect to the vertical upstream face or with some reference line.

(2) Water pressure - On the upstream face the pressure is exerted by the water stored up to full reservoir level and on the downstream face the pressure is exerted by the tail water. Again, the upstream face of the dam may be completely vertical or partly vertical and partly inclined. But the downstream face is always inclined.

(3) Uplift pressure - The stored water on the upstream side of the dam has a tendency to seep through the soil below the foundation. While seeping, the flowing water exerts uplift pressure on the base of the dam which depends on the head of water. This uplift pressure reduces the self weight of the dam.

(4) Seismic force - When the selected dam site comes under the seismic zone the effect of earthquake waves should be taken into account as it endangers the structure. The vertical and horizontal components of the earthquake waves are considered for the design of a dam coming in seismic zone. The acceleration of earthquake waves consist of two components vertical acceleration (f_v) and horizontal acceleration (f_h). These accelerations depend on the coefficient (c_v or c_h) which is expressed as the percentage of acceleration due to gravity g i.e. as 0.1g, 0.2g .... etc.

(5) Silt Pressure - The silt carried by the river and its tributaries gets deposited against the upstream base of the dam year after year. After considerable deposition of silt, it exerts pressure on the dam. So provisions should be made to resist this silt pressure. The upstream face of the dam may be completely vertical or partly vertical and partly sloping. So, the pressure of silt will differ accordingly.

(6) Wave Pressure - When very high wing or tornado flows over the water surface of the reservoir, waves are formed which exert pressure on the upper part of the dam. The magnitude of the wave depends on the velocity of wind, depth of reservoir and the area of water surface.

(7) Ice Pressure - This pressure should be counted only in places where the formation of ice is expected on the reservoir surface. When the sheet of ice is formed on the entire water surface of the reservoir, then it exerts pressure on the dam at the point of contact during the process of contraction and expansion with the change of temperation.

(8) Wind Pressure - The top exposed portion of the dam is not much and the wind pressure on the surface area of this portion is negligible But still an allowance should be made for the wind pressure at the rate of about 150 kg/m² for the exposed surface area of the upstream and downstream faces.

Causes of failure of gravity dam :-

The solid gravity dam may fail, because of the following reasons:

(1) By over turning - The slild gravity dam may fail by over turning at its toe when the total horizontal forces acting on the dam are greater than the total vertical force. In such a case, the resultant force passes through a point outside themiddle third of the base of the dam. The overturning may be caused at the downstream edge of any horizontal section.

(2) By sliding - The total horizontal forles acting on a dam tend to slide the entire dam at its base or along any horizontal section of the dam. The sliding may take place. when the total horizontal forces on the dam are greater than the combined resistance offered by shearing resestance of the joint and the static friction.

(3) By over stressing - If the permissible working compressive stress of concrete or masonary exceeds due to some adverse conditions, then the dam may fail byt crushing due to overstressing of the concrete or masonry.

(4) By cracking - The tensile stresses should not be allowed to develop on the upstream face of the dam. If due to some reasons the tension is developed inthe dam section. crack will form in the body of the dam and ulimately this will cause the failure of the dam.

Precautions against failure :-

(1) To avoid overturning, the resultant of all forces acting on the dam should reamin within the middle-third of the base width of the dam. This condition should be achieved in both the cases, when the reservoir is full and also when it is empty.

(2) In the dam, the sliding should be fully resisted when the condition for no sliding exists in the dam section.

The condition for no sliding is given by

$$\tan\theta = \frac{\Sigma p}{\Sigma w}$$

and $\tan\theta \angle \mu$.

Where, Σp = sum of horizontal forces

Σw = sum of vertical forces.

μ = coefficient of friction of the materials of dam.

(3) In the dam section, the compressive stresses of concrete or masonry should not exceed the permissible working stresses to avoid failure due to crushing.

(4) There should be no tension in the dam section to avoid the formation of cracks. This condition may be achieved by main taining the middle-third rule.

(5) The factor of safety should be taken 4 to 5.

Ans. The failure of the earthen dam may be caused due to the following reasons.

1. **Hydraulic failure** – This type of failure may be caused by :

   a. **Overtopping** : If the actual flood discharge is much more than the estimated flood discharge or the free board is kept insufficient or there is settlement of the dam or the capacity of spill way is insufficient, then it results in the ovetopping of the dam. During the ovetopping the crest of the dam may be washed out and the dam may collapse.

   b. **Erosion** : If the stone protection of the upstream side is insufficient, then the upstream face may be damaged by erosion due to wave action. The downstream side also may be damaged by tail water, rainwater etc. The toe of the dam may also get damaged by the water flowing through the spill ways.

2. **Seepage failure** : This type of failure may be caused by :

   (i) **Piping or undermining** : Due to the continuous seepage flow through the body of the dam and through the sub-soil below the dam, the downstream side gets eroded or washed out and a hollow pipe like groove is formed which extends gradually towards the upstream through the base of the dam. This phenomenon is known as piping undermining. This effect weakens the dam and ultimately causes the failure of the dam.

   (ii) **Erosion** : If the stone protection of the upstream side is insufficient, then the upstream face may be damaged by erosion due to wave action. The downstream side also may be damaged by tail water, rainwater etc. The toe of the dam may also get damaged by the water flowing through the spill ways.

3. **Seepage Failure** : This type of failure may be caused by :

   (i) **Piping or undermining** : Due to the continuous seepage flow through the body of the dam and through the sub-soil below the dam, the downstream side gets eroded or washed out and a hollow pipe like groove is formed which extends gradully towards the upstream through the base of the dam. This phenomenon is known as piping or undermining. This effect weakens the dam and ultimately causes the failure of the dam.

4. **Sloughing** : The crumbling of the toe of the dam is known as sloughing. When the reservoir runs fullm for a longer time, the downstream base of the dam remains saturated. Due to the force of the seepage water the toe of the dam goes on crumbling gradually. Ultimateiy the base of the dam collapses.

5. **Structural Failure** : This type of failure may be caused by

   (i) **Sliding of the side slopes** : Sometimes, it is found that the side slope of the dam slides down to form some steeper slope. The dam goes on depressing gradually and then overtopping occurs which leads to the failure of the dam.

   (ii) **Damage by burrowing animals** : Some burrowing animals like craw-fish, snakes squirrel, rates etc cause damage to the dam by digging holes through the foundation and body of the dam.

   (iii) **Damage by earthquake** : Due to earthquake cracks may develop on the body of the dam and the dam may eventually collapse.

(b) Write short notes on gravity dam.

Ans. A gravity dam is constructed with masonry or concrete. It resists the forces acting on it by its own weight. It is approximately triangular in section. The up-stream and down-stream faces are finished with rich cement mortar. The distance between the heel and toe is considered as the base width. It depends on the height of the dam. If good rocky foundation is available, the height may be above 200 m. It hard foundation is not available, the height of the dam should be limited to about 20 m. The up-stream and down-stream base of the dam is made sloping. The horizontal trace passing through the up-stream top edge is known as axis of the dam or the base line. The forces acting on gravity dam are weight of the dam, water pressure, uplift pressure, seismic force, silt pressure, wave pressure, ice pressure, and wind pressure. The causes of failure of gravity dams are by over-turning, by sliding, by over stressing, and by cracking. The precautions against failures are to avoid over-turning, the resultant of all forces acting on the dam should remain within the middle-third of the base width of the dam. The factor of safety should be taken 4 to 5. There should be no tension in the dam section to avoid the formation of cracks.

(c) Differentiate between a syphon aqueduct and