UNIT – 4

CONCEPT:-

Embankment dams are made of earth material and are suitable for situations where the valley is wide and the foundation is weak rock or thick soil deposit and/or the abutments are also weak. This type of dam is more flexible than the rigid dam and can withstand some degree of foundation deformation more easily.

Embankment dams can be of two types:

(i) Earthfill dams

(ii) Rockfill dams

While earthfill dams or earth dams as they are generally called comprise primarily of soil material, rocks form the bulk in a rockfill dam. The design principles of both these being similar, only those for the earth dams are discussed here.

Earth dams can also have two types of sections viz. homogeneous or zoned.

Homogeneous earth dams are constructed of only one type of material and are used only when the height of the dam is small and only one type of material is available economically. In case the height of the dam exceeds about 6m, a modified homogeneous section is used. The modified homogeneous section has some drainage arrangement provided at the downstream side to provide stability as well as help in controlling the effects of seepage.

Zoned earth dams consist of an impervious core flanked by zones of more pervious material called the shelll. The permeability of the material goes on increasing as one moves away from the core. This is the most common type of earth dam and many high earth dams such as Nurek (300m), Oroville (224m) and Ramganga (125m) are of this type. The impervious core may be centrally placed or sloping. Both have their advantages or disadvantages depending on the site conditions and availability of material. While the core makes the section impervious thereby reducing seepage through the dam, the shell supports and protects the core. The top width of the dam depends on the height and typically varies from about 2.5m to 6m but can be much more for high dams.

CRITERIA FOR SAFETY OF EARTH DAMS

The design of earth dams is carried out to conform to the criteria of safety for the same. These are based on observations on existing dams and study of failures. The main criteria can be listed as below:

(i) No overtopping i.e. water must not flow over the dam under any circumstances as this could lead to certain failure of the dam.

(ii) The slopes, both upstream and downstream must be stable under all conditions

(iii) The upstream face must be protected against the action of waves and the downstream one against action of rain.

(iv) The seepage line must be well within the downstream face

(v) There should be no free flow of water through the dam body.

(vi) The seepage through the foundations must be controlled and not allowed to cause piping

(vii) The foundation shear should be within permissible limits

SAFETY AGAINST OVERTOPPING

Majority of the failures of earth dams have been a result of overtopping. In order to avoid this, two steps are necessary. The first involves providing adequate spillway capacity. Liberal provision of spillway capacity in earth dams as compared to rigid dams is mostly resorted to in order to keep the maximum reservoir level within estimated limits. The second step is to provide adequate freeboard – the vertical distance between the dam crest and the still water level in the reservoir. Since the normal reservoir level will be less than the maximum reservoir level i.e. the level when the design flood occurs, the freeboard with respect to the former is termed as the normal freeboard while that with respect to the latter is called the minimum freeboard. The freeboard is also supposed to take into account the safety against overtopping due to the settlement of the dam and foundations. The parameters on which the computation of freeboard is based are the wave height, wave run up and wind set up with an additional margin added for uncertain effects such as settlement, earthquakes etc. The freeboard is given by:

Freeboard = Greater of design wave height or wave run up + wind set up + margin for uncertain effects

The computation for design wave height requires determination of the effective fetch f_e and the wind velocity V for the reservoir. The wave height is then determined by:

$$gH_w/V^2 = 0.0026\ (gf_e/V^2)^{0.47}$$

in which H_w is the wave height in metres, V the wind velocity in m/s and f_e the effective fetch in metres, g being the acceleration due to gravity. The design wave height H_d is taken as 1.67 times the value H_w obtained from the above formula.The wave run up R depends on the design wave height, the ratio of design wave height to wave length and the embankment slope and roughness and can be determined from curves relating the first three and correction factors available for roughness. The greater of H_d and R is used in computing the freeboard with the proviso that it should not be less than 2.0m for both the normal and minimum freeboard.

STABILITY OF SLOPES

Both the upstream and downstream slopes of an earth dam need to be tested for their stability under different conditions. The conditions for which the testing is required are listed below:

(i) End of construction

Soils derive their strength for withstanding shear from cohesion and friction. The friction is a result of the effective stress between soil particles.The pore spaces between the soil particles are filled with water and this exerts a pressure called pore pressure. The effective intragranular stress is the total stress minus the pore pressure. The shear strength of the soil can be given by:

$$s = c + (\sigma - u) \tan \phi$$

In which s is the shear strength, c the cohesion, σ the total stress, u the pore water pressure and ϕ is the angle of internal friction for the soil.

During construction, soil is compacted after pouring water over it and therefore large pore pressures develop, thereby reducing the effective stress and hence the shear strength. The pore pressures dissipate with time and the shear strength increases. In case of rapid mechanized

construction, there is not enough time for the pore pressures to get dissipated and hence it is important to ensure the stability of slopes during construction as well as at the end of construction.

(ii) Reservoir partially filled

The stability of the upstream slope needs to be checked for the condition when the reservoir is partially filled. This is so because under this condition, the upstream slope will be partly submerged and partly dry. The checking is generally done at different levels of water in the reservoir.

(iii) Sudden drawdown

This condition pertains to the rapid removal of water from the reservoir. If a full reservoir is suddenly emptied, the upstream face will not have any weight of water on it thereby reducing the intragranular stress. The pore water pressure will however correspond to the full reservoir level and will take time to dissipate. The effective stress will thus be reduced considerably resulting in decreased shear strength which could lead to the failure of the upstream slope. The upstream slope is therefore checked for this condition.

(iv) Steady seepage

When the reservoir is full and seepage is taking place through the dam, the downstream slope is affected by the seepage. It therefore needs checking for the case of steady seepage.Besides the above, the stability of slopes also to be ensured for conditions such as earthquake, heavy rainfall with seepage etc. These are however not included in the present discussion.

Method of Stability Analysis

There are many methods of analysis for determining the stability of slopes. However, only the method of slices, also called the Swedish method will be discussed here. In this method, like in many others also, a surface of failure of embankment is assumed and the factor of safety for the same worked out. This process is repeated with a number of trial surfaces and the one with the least factor of safety is called the critical slip surface. If the factor of safety for the critical slip surface is more than one, the slope is taken to be stable. The Swedish method assumes that the slip surface is an arc of a circle. Some guidelines for getting the critical slip circle are also available, which serve to reduce the trials in as much as one could assume slip circles in the vicinity of the one predicted by these guidelines and choose the one with the smallest factor of safety.

The following procedure is adopted for analyzing the stability along an assumed slip circle :

(i) The assumed slip circle is divided into a number of slices. The arc at the bottom of a slice should normally be contained wholly in one type of material.

(ii) For each slice, assuming unit length of the dam, the actuating and resisting forces are computed. This is done as follows:

(a) The weight of the slice W is the volume multiplied by the appropriate unit weight.

(b) The normal component of this weight N is given by W cosα, while the tangential component T is W sinα.

(c) The uplift force U acts at the bottom of the slice and can be given by ub/cosα, where u is the average unit pore pressure, b the width of the slice and α is the angle that the normal to the bottom of the slice makes with the vertical.

(d) The net normal force thus is (N-U) and results in a shear strength of (N-U) tanϕ.

(e) The shear strength due to cohesion C is cb/cosα and therefore the total shear strength is C + (N-U) tanϕ, where ϕ is the angle of internal friction.

(f) As is clear from the free body diagram of a slice as shown, the actuating force i.e. one which tends to cause the sliding is T, while the resisting force is C+(N-U) tanϕ.

(g) There are also forces F_L and F_R acting on the left and right side of the slice. It is difficult to estimate these and they are generally assumed to cancel out.

(iii) The computations are carried out in a tabular form and the sum of the actuating and resisting forces S and T is obtained.

(iv) The factor of safety is computed as

$$F.S. = \sum S / \sum T$$

In case the pore water pressures are not directly taken into account in the analysis i.e. if u is ignored, the same can be indirectly taken care of to some extent by using the submerged unit weight of the soil for computation of the resisting forces and the saturated weight for computing the actuating forces for the soil mass below the phreatic line. The moist weight is used in computing these for the soil mass above the phreatic line.

The factor of safety for both the upstream and downstream slopes for all conditions must be greater than one, though the actual acceptable value will depend on a number of factors such as the condition under which the slope is being tested, the shape and size of the dam, the site conditions etc.

In addition to being stable, the upstream slope of the dam has to be protected against wave action. This is generally done by providing stone pitching on the upstream slope or providing dumped rip rap over a suitable filter. Likewise, the downstream slope needs protection against rain, which can cause deep gullies on this slope. The best protection against rain is turfing – growing grass over this face. In situations where this is not feasible for one reason or the other, the downstream face is also protected with pitching or dumped rip rap.

SEEPAGE CONSIDERATIONS

An earth dam being composed of earth material, water is bound to seep through it as well as through the foundations. Though an impervious core is provided in the earth dams, this is never truly impervious, but only has a low permeability compared to the shell. Certain quantity of water thus will seep through the core also. Controlling the quantity of seepage and the effects of seepage through the dam and its foundations is thus very important both from the point of view of water conservation as well as the

safety of the dam.

The two dimensional seepage through homogeneous, isotropic and incompressible porous media is governed by the Laplace equation

$$(\partial^2 h/\partial x^2) + (\partial^2 h/\partial y^2) = 0$$

Where h is the seepage head.

The solution of the aforesaid equation with appropriate boundary conditions will therefore yield all the needed information about the seepage through an embankment dam or its foundations. There are various means of solving the equation including the graphical,analytical and numerical methods. The present discussion will be confined mainly to the graphical method and results obtained therefrom.

The graphical method of solving the Laplace equation involves drawing the flownet for given boundary conditions. In the case of an embankment dam, the topmost streamline, also called the phreatic line is not known beforehand and hence the difficulty in drawing the flownet. The discharge per unit length of the dam will then be given by

$$q = K (\sqrt{(d^2 + h^2)} - d)$$

where K is the coefficient of permeability of the embankment material.

However, since the actual embankment dam sections do not have a parabolic upstream face or may not have a filter which is horizontal, the phreatic line in such cases will not be given by the Kozeny's parabola (also referred to as the base parabola).

Casagrande obtained the flownets for a variety of sections of embankment dams and found that the phreatic line by and large followed the base parabola with departures at the entrance and exit points. Thus, while for a homogeneous section with no drains, the base parabola will have its focus at the point D , it will start at a point H where EH is equal to 0.3 EK. The actual phreatic line will however, start at the point E, normal to the face AB and take a reverse curve to join the base parabola tangentially. At the exit end, the actual phreatic line will join the face CD tangentially at I, while the base parabola cuts this face at J. The value of $\Delta a/(a+\Delta a)$ for different values of the angle α has been given by Casagrande.

In case the section has a drain other than horizontal such as a rock toe, the focus of the base parabola will be at F and the starting point will be at H as for the case discussed above. The corrections at the entry and exit will also be determined in a manner similar to what has been discussed above.Having drawn the phreatic line, the complete flownet can be drawn for the embankment and the requisite information regarding seepage through the same obtained.

with the value of d being taken as the horizontal distance between the point H and the focus of the base parabola.

For a zoned embankment section, generally the shell is many times more permeable than the core and hence the aforesaid analysis needs to be done for the core only, which can be taken as homogeneous. Analysis on lines similar to the above can also be carried out if the above condition is not satisfied or in cases where there is a variation of permeability in the horizontal and vertical directions. These cases have, however not been discussed here.

As already mentioned, all earth dams are provided with some drainage at the downstream end. This ensures that the phreatic line does not cut the downstream face thereby preventing the chances of sloughing of the downstream slope. In addition, such a

drain also controls the outgoing seepage water such that it does not remove soil particles i.e. prevents piping.The seepage through the foundations can become an important parameter, specially if the dam is founded on pervious material and can be analysed using a flownet. Reduction of the quantity of water seeping through the foundations is important in such cases. This can be done by use of cutoffs- partial or complete. The cutoff can be a rolled earth one, which is economical if the depth of the pervious foundation is relatively small, with a partial cutoff being effective only to a limited extent. Other means such as a slurry trench filled with clay and bentonite mixture, sheet piles or concrete cut off wall can also be used for somewhat larger depths of pervious material.

In case the depth of the pervious strata is large, a horizontal impervious blanket can be used to reduce the quantity of seepage through the foundations. The horizontal blanket is provided on the upstream side and consists of relatively impervious material with thickness of the order of 0.75m to even 3m or more.

In the absence of the blanket, the seepage discharge through the foundation can be given by $Q = K_f (H/x_c)D_f$

where K_f and D_f are the permeability and depth of the foundation respectively.

If a blanket of length x_b is provided as shown, the discharge through the foundation is given by

$$Q_b = K_f ((H/(x_c+x_b))D_f$$

The reduction in discharge p is thus

$$p = Q_b/Q = x_c/(x_c+x_b)$$

It may however be mentioned that the above is a simplified analysis and the effectiveness of the blanket will reduce with increasing length.

The seepage water should not get a free flow path through the body of the dam, because in such a case the flowing water can dislodge soil particles and create a cavity within the dam body by piping. This could ultimately lead to the failure of the dam. Such a free flow path can generally be available along the outside of outlet pipes etc. embedded within the dam and as such these are best avoided in an earth dam. In case it becomes necessary to embed the same, extreme care has to be taken.

FOUNDATION SHEAR

The foundation of an embankment dam must be safe in shear. Thus the shear strength of the foundation material should be more than the shear to which it is subjected. The distribution of shear on the foundation is not uniform. The factor of safety being the ratio between the shear strength and the shear intensity, it will vary with the distribution and should be more than one at the location of maximum shear. Simplified procedures are available, which can give a good idea of the shear as well as its distribution and should be used to check the safety of the foundation.

Design Procedure

The design of an embankment dam starts with an assumed section based on the availability of material, foundation conditions etc. and its modification based on the criterion of safety as discussed above. Economy also plays a very important role in selecting from a number of alternatives available before the section is finalized

Gravity dams	Gravity dams are rigid dams which ensure stability against all loads by virtue of their weight alone
Dead Load (W_D)	The dead load includes the weight of the dam and is transmitted directly to the foundations.
Uplift force	There is always some seepage within the body of the dam as well as through the foundations and this gives rise to an uplift force (U) acting vertically upwards
Earthquake Force	Earthquakes impart a horizontal as well as a vertical acceleration to the dam and the stored water. This results in additional forces, both in the horizontal and vertical directions.
Embankment dams	Embankment dams are made of earth material and are suitable for situations where the valley is wide and the foundation is weak rock or thick soil deposit and/or the abutments are also weak.
Homogeneous earth dams	Homogeneous earth dams are constructed of only one type of material and are used only when the height of the dam is small and only one type of material is available economically
Zoned earth dams	Zoned earth dams consist of an impervious core flanked by zones of more pervious material called the shell

The building of a dam and the filling of the reservoir behind it places a new weight on the floor and sides of a valley. The stress of the water increases linearly with its depth. Water also pushes against the upstream face of the dam, a nonrigid structure that under stress behaves semiplastically, and causes greater need for adjustment (flexibility) near the base of the dam than at shallower water levels. Thus the stress level of the dam must be calculated in advance of building to ensure that its break level threshold is not exceeded.[4]

Overtopping or overflow of an embankment dam beyond its spillway capacity will cause its eventual failure. The erosion of the dam's material by overtopping runoff will remove masses of material whose weight holds the dam in place and against the hydraulic forces acting to move the dam. Even a small sustained overtopping flow can remove thousands of tons of overburden soil from the mass of the dam within hours. The removal of this mass unbalances the forces that stabilize the dam against its reservoir as the mass of water still impounded behind the dam presses against the lightened mass of the embankment, made lighter by surface erosion. As the mass of the dam erodes, the force exerted by the reservoir begins to move the entire structure. The embankment, having almost no elastic strength, would begin to break into separate pieces, allowing the impounded reservoir water to flow between them, eroding and removing even more material as it passes through. In the final stages of failure the remaining pieces of the embankment would offer almost no resistance to the flow of the water and continue to fracture into smaller and smaller sections of earth or rock until these would disintegrates into a thick mud soup of earth, rocks and water.

Therefore, safety requirements for the spillway are high, and require it to be capable of containing a maximum flood stage. It is common for its specifications to be written such that it can contain a five hundred year flood.[5] Recently a number of embankment dam overtopping protection systems have been developed.[6] These techniques include the concrete overtopping protection systems, timber cribs, sheet-piles, riprap and gabions, reinforced earth, minimum energy loss weirs, embankment overflow stepped spillways and the precast concrete block protection systems.

A **gravity dam** is a dam constructed from concrete or stone masonry and designed to hold back water by primarily utilizing the weight of the material alone to resist the horizontal pressure of water pushing against it. Gravity dams are designed so that each section of the dam is stable, independent of any other dam section.[1][2]

Gravity dams generally require stiff rock foundations of high bearing strength (slightly weathered to fresh); although they have been built on soil foundations in rare cases. The bearing strength of the foundation limits the allowable position of the resultant which influences the overall stability. Also, the stiff nature of the gravity dam structure is unforgiving to differential foundation settlement; which can induce cracking of the dam structure.

Gravity dams provide some advantages over embankment dams. The main advantage being that they can tolerate minor over-topping flows as the concrete is resistant to scouring. Large over-topping flows are still a problem, as they can scour the foundations if not accounted for in the design. A disadvantage of gravity dams is that due to their large footprint, they are susceptible to uplift pressures which act as a de-stabilising force. Uplift pressures (buoyancy) can be reduced by internal and foundation drainage systems which reduces the pressures.

During construction, the setting concrete produces a exothermic reaction. This heat expands the plastic concrete and can take up to several decades to cool. When cooling, the concrete is in a stiff state and is susceptible to cracking. It is the designer's task to ensure this does not occur.

The most common classification of gravity dams is by the materials composing the structure:

- Concrete dams include
  - mass concrete dams, made of:
    - conventional concrete: Dworshak Dam, Grand Coulee Dam
    - Roller-Compacted Concrete (RCC): Willow Creek Dam (Oregon), Upper Stillwater Dam
  - masonry: Pathfinder Dam, Cheesman Dam
  - hollow gravity dams, made of reinforced concrete: Braddock Dam

Composite dams are a combination of concrete and embankment dams.[*citation needed*] Construction materials of composite dams are the same used for concrete and embankment dams.

Gravity dams can be classified by plan (shape):

- Most gravity dams are straight (Grand Coulee Dam).
- Some masonry and concrete gravity dams have the dam axis curved (Shasta Dam, Cheesman Dam) to add stability through arch action.[3]

Gravity dams can be classified with respect to their structural height:

- Low, up to 100 feet.

- Medium high, between 100 and 300 feet.
- High, over 300 feet.

IMPORTANT QUESTIONS:-

1. a) Explain the various seepage control measures in an earth dam
   b) Explain about earth dams and rock fill dams with the help of neat sketches and also write its advantages and disadvantages
2. a)Enumerate the various modes of failure in a gravity dam
   b) Explain the various seepage control measures in Earth dams.
3. Give few lines defining Gravity dam? Explain the various forces acting on a gravity dam.
4. Explain the methods of construction of Earth dams. Write the merits & demerits of Earth dams
5. a)List the various forces acting on a gravity dam. Explain earthquake pressure in detail
   b) Explain overturning and sliding of a gravity dam
6. a) Enumerate the various modes of failure in a gravity dam
   b) Explain the design criteria for Earth dams