Section-C

Unit-IV (Storage Headworks)

* Types of dams :→
1) Earth Dams
2) Rock-fill Dams
3) Solid Masonry Dams

1) Earth dams:→

Earth dams are made of soil that is pounded down solidly. They are built in areas where the foundations is not strong enough to bear the weight a concrete dam, and where earth is more easily available as a building material compared to concrete or stone or rock.

Types:- Pg. 786
(i) Homogeneous Embankment type
(ii) Zoned Embankment type
(iii) Diaphragm type

(i) Homogeneous Embankment Type :→

It is the simplest type of an earthen embankment consists of a single material and is homogeneous throughout. A purely homogeneous section is used when only one type of material is economically or locally available. Such a section is used for low to moderately high dams and for levees. Large dams are seldom designed as homogeneous embankment.

(ii) Zoned Embankment type :→

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

(iii) Diaphragm type :→

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 u/s face as a blanket.

Methods :-

(i) Hydraulic-fill method
(ii) Rolled-fill method

2) Rockfill Dams :→

They are less flexible than earthen dams and more flexible, then gravity dams. Their foundation requirements are not strict and rigid as are required for gravity dams. But the foundation requirements are more rigid than those for earthen dams which can be constructed almost on any types of foundations. The steeper slopes are used in rockfill dams and hence, the base width is quite ~~too~~ less. The smaller base width and the possibility of large scale seepage restricts the foundation requirement of such dams.

3) Solid-Masonry Gravity Dams:→

These are familiar to us by now. These big dams are expensive to be built but are more durable and solid than earth and rock dams. They can be constructed on any dam site, where there is a natural foundation strong enough to bear the great weight of the dam.

* In recent times, four other types of dams have come into practice. They are:

(1) Hollow masonry gravity dams

(2) Timber dams

(3) Steel dams

(4) Arch dams

(1) Hollow masonry gravity dams:→

These are essentially designed on the same lines on which the solid masonry gravity dams are designed. But they contain less concrete or masonry, about 35 to 40% or so. Generally, the weight of water is carried by a deck of R.C.C. or by arches that share the weight burden. They are difficult to build and are adopted only if very skilled labour is easily available, otherwise the labour cost is too high to build its complex structure.

(2) Steel dams:→
These are not used for major works. Today, steel dams are used as temporary coffer dams needed for the construction of permanent dams. Steel coffer dams are usually reinforced with timber or earthfill.

(3) Timber dams:→
Their life is not more than 30 to 40 years and must have regular maintenance during that time. However, they are valuable in agricultural areas

(4) Arch dams:→
These are very complex and complicated. They make use of the horizontal arch action in place of weight to hold back the water. They are best suited at sites where the dam must be extremely high and narrow.
Eg:- The Tignes dam in France (592' high)
Idduki dam in Kerla

※ ~~Selection of a site:→~~
or
※ Selection of a Particular type of dams:→
Factors :-
(1) Topography:→
It dictates the first choice. For example:
(i) A narrow, U-shaped valley i.e. a narrow stream flowing between high rocky walls, would suggest a concrete overflow dam.

(2) Geology and Foundation Conditions :-
The foundation have to carry weight of the dam. The dam site must be throughly surveyed by geologists, so as to detect the thickness of the foundation strata; presence of faults, fissured material and their permeability, slope and slip etc.

3) Availability of materials :->
In order to achieve economy in the dam, the material required for its construction must be available locally or at short distance from the construction ratio.

4) Spillway Size and Location :->
Spillway, diposes of the surplus river discharge. The Capacity of the spillway will depend on the magnitudes of the floods to be by-passed. The spillway, therefore, become much more important on streams with large flood potential.

(5) Earthquake Zone :->
If the dam is to be constructed in an earthquake zone, its design must include the earthquake forces. Its safety should be ensured against the increased stress.

(6) Height of the dam :->
Earthen dams are usually not provided for heights more than 30 m or so. Hence, for greater heights, gravity dams are generally preferred.

Selection of Dam Site :→ Pg. 643

Factors :-

(i) Suitable foundations must be available

(ii) For economy, length of the dam should be as small as possible, and for a given height, it should store the max. volume of water.

(iii) The general bed level at dam site should preferably be higher than that of the river basin. This will reduce the height of the dam and will facilitate the drainage problem.

(iv) A suitable site for the spillway should be available in the near victinity.

(v) Material required for the construction should be easily available.

(vi) The reservoir basin should be reasonably water-tight.

(vii) The value of land and property submerged by the proposed dam should be as low as possible.

(viii) The dam site should be easily ~~available~~ accessible.

(ix) Site for establishing labour colonies and a healthy environment should be available in the near victinity.

Arch Dams :→

An arch dam may be defined as a solid wall, curved in plan, standing across the entire width of the river valley, in a single span. This dame body is usually made of cement concrete, although rubble and stone masonry has also been used in the past.

Eg :→ Idduki dam in kerla

Note:— ⊠
When multiple or a number of arches are used, supported between intermediate piers, the dam is known as a buttress dam.

Depending upon the shape consideration, simple arch dams can be divided into three types:—
(i) Constant radius arch dams
(ii) Variable radius arch dams
(iii) Constant angle arch dams

(i) Constant radius arch dams:→
A constant radius with arch dam is that, in which, the radii of the outside curved surface are equal at all elevations, from top to the bottom. The centres of all such circular arcs, called extrodes, will therefore, evidently lie on on vertical line. However, the introdes has gradually decreasing radius from top to the bottom. The dam body will be triangular in cross-section with u/s face vertical, and a minimum thickness at the top.

(ii) Variable radius arch dams:→
A variable radius arch dams is the one in which the radii of the extrodes curves and of introdes curves vary at various elevations, being maximum at the top, and a certain minimum at its bottom. This makes the central angles as large as possible, so that the maximum arch efficiency may be obtained at all elevations.

(iii) Constant angle arch dams:→

The constant angle arch dam is a special type of variable radius arch dam, in which the central angles of the horizontal arch rings are of the same magnitude at all elevations. The design of such a dam can be made by adopting the best central angle of 133°-34°, and hence such a dam proves to be the most economical, out of three types of ordinary arch dams

[*] Forces Acting:→ Pg. 726

Generally, the same forces act on the arch dam, which do act on a gravity dam.

The various forces acting are:-

(1) Water Pressure (2) Uplift Pressure
(3) Pressure due to Earthquake
(4) Silt Pressure (5) Wave Pressure
(6) Ice Pressure
(7) The stabilishing force is the weight of the dam itself

(1) Water Pressure:→ (P)

It is the most major external force acting on such a dam. The horizontal water pressure, exerted by the weight of the water stored on the u/s side on the dam can be estimated from rule of hydrostatic pressure distribution, which is trangular in shape. When the u/s face is vertical, the intensity is zero at the water surface and equal to $\gamma_w H$ at the base

where, γ_w = Unit weight of water
H = Depth of water

The resultant force due to this external water $= \frac{1}{2}\gamma_w H^2$, acting at $H/3$ from base.

(2) Uplift Pressure:→

Water seeping through the pores, cracks and fissures of the foundation material, and water seeping through dam body and then to the bottom through the joints between the body of the dam and its foundation at the base; exert an uplift pressure on the base of the dam. Such an uplift force virtually reduces the downward weight of the body of the dam and hence, acts against the dam stability.

(3) Earthquake Forces:→

An earthquake produces waves which are capable of shaking the Earth upon which the dam is resting, in every possible direction.

The effect of an earth is equivalent to imparting an acceleration to the foundation of the dam in the direction in which the waves is travelling at the moment.

Earthquake wave may move in any direction, and for design purposes, it has to be resolved in vertical and horizontal components. Hence, two accelerations, i.e. one horizontal acceleration (α_h) and one vertical acceleration (α_v) are induced by an earthquake.

(4). Silt Pressure:→

Silt gets deposited against the ~~up~~ u/s face of the dam. If h is the height of silt deposited, then the force exerted by this silt in addition to external water pressure, can be represented by Rankine's formula as:

$\therefore P_{silt} = \frac{1}{2}\gamma_{sub} \cdot h^2 K_a$ and acts as $\frac{h}{3}$ from base

where, K_a = Coefficient of active earth pressure of silt $= \frac{1-\sin\phi}{1+\sin\phi}$ where ϕ is the angle of internal friction of soil, and cohesion is neglected

γ_{sub} = Submerged unit weight of silt material

h = height of silt deposited.

If the u/s face is inclined, the vertical weight of the silt supported on the slope also acts as a vertical force.

(5) Wave Pressure :→

Waves are generated on the surface of the reservoir by the blowing winds, which causes a pressure towards the d/s side. Wave pressure depends upon the wave height. Wave height may be given by

$$h_w = 0.032\sqrt{V \cdot F} + 0.763 - 0.271(F)^{1/4} \text{ for } F < 32 \text{ km, and}$$

$$h_w = 0.032\sqrt{V \cdot F} \text{ for } F > 32 \text{ km}$$

where, h_w = height of water from top of crest to bottom of the trough (m)

V = Wind Velocity in km/hr.

F = Fetch or straight length of water expanse (km)

The maximum pressure intensity due to wave action may be given by $P_w = 2.4\,\gamma_w \cdot h_w$ and acts at $\frac{h_w}{2}$ metres above the still water surface.

The pressure distribution may be assumed to be triangular, of height $\frac{5h_w}{3}$

Hence, the total force due to wave action (P_w)

$$= \frac{1}{2}(2.4\gamma_w h_w) \cdot \frac{5}{3} h_w$$

or, $P_w = 2\gamma_w h_w^2 = 2 \times 9.81\, h_w^2$ KN/m

$= 19.62\, h_w^2$ KN/m

This force acts at a distance $\frac{3}{8} h_w$ above the reservior surface.

(6) Ice Pressure :→

The ice which may be formed on the water surface of the reservoir in cold countries, may sometimes melt and expand. The dam face has then to resist the thrust excerted by the expanding ice. This forces acts linearly along the length of the dam and at the reservoir level. The magnitude of this force varies from 250 to 1500 KN/m^2 depending upon temperature variations.

(7) Weight of the dam :→

The weight of the dam body and its foundation is the major resisting force. In two dimensional analysis of a gravity dam, a unit length of the dam is considered. The cross-section can then be divided into rectangles and triangles. The weight of each along with their c.gs can be determined. The resultant of all these downward forces will represent the total weight of the dam acting at the c.gs of the dam.

⊠ Gravity method or Two Dimensional Stability Analysis:→

Pg. – 742

The dam is considered to be made up of a number of cantilevers of unit width each, which act independently of each other. This assumption of independent functioning of each section, disgards the beam action in the dam as a whole.

If the vertical transverse joints of the dam are not grouted or Keyed together this assumption is nearly true. Hence, for wide U-shaped valleys, where transverse joints are not generally graited, this assumption is nearly satisfied. But for narrow V-shaped, where the transverse joints are generally keyed together, this assumption may involve appreciable errors.

Assumptions:→

1) The dam is considered to be composed of a number of cantilevers, each of which is 1 m thick and each of which acts independent of the ~~ot~~ other.

(ii) No loads are transferred to the abutments by beam action.

(iii) The foundation and the dam behave as a single unit; the joint being perfect.

(iv) The materials in the foundation and body of the dam are isotropic and homogeneous.

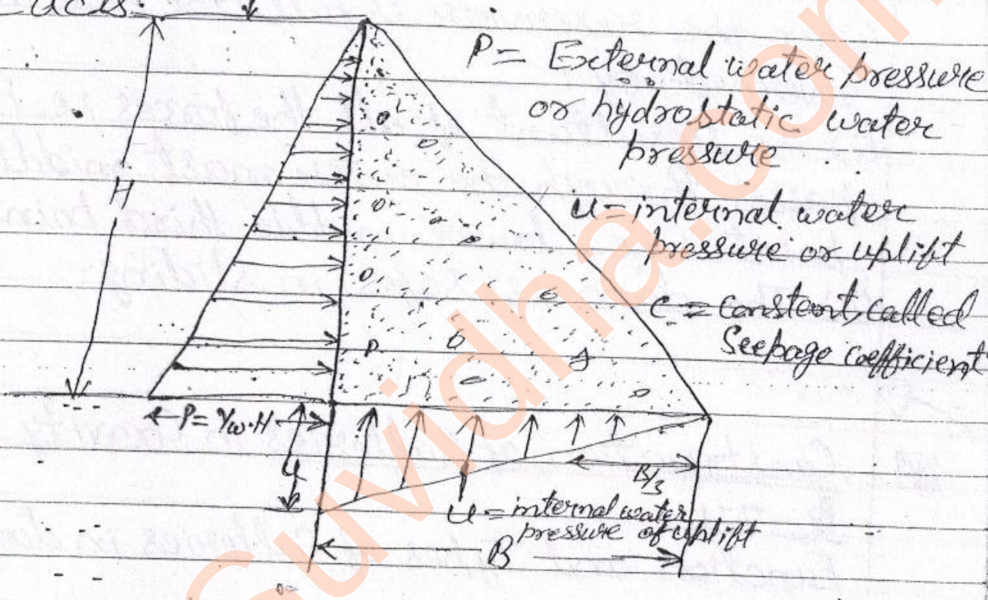
(v) The stresses developed in the foundation and body of the dam are within elastic limits.

(vi) No ~~moments of~~ movements of the foundations are caused ~~by~~ due to transference of loads.

(vii) Small openings made in the body of the dam do not affect the general distribution of stresses.

Elementary profile of a Gravity Dam :→ Pg. 744

The elementary profile of a dam, subjected only to external water pressure on the u/s side, will be a right-angled triangle, having zero width at the water level and a base width (B) at bottom i.e. the point where the maximum hydrostatic water pressure acts.



When the reservoir is empty, the only single force acting on it is the self-weight (W) of the dam and it acts at a distance B/3 from the heel. This is the maximum possible innermost position of the resultant for no tension to develop. Hence, such a line of action of W is the most ideal, as it gives the maximum possible stablishing moment about the toe without causing tension at toe, when the reservoir is empty. The vertical stress distribution at the base, when the reservoir is empty, is given as:

$$P_{max/min} = \frac{\Sigma V}{B}\left[1 \pm \frac{6e}{B}\right], \text{ Here } \Sigma V = W \ \& \ e = \frac{B}{6}$$

$$\therefore P_{max/min} = \frac{W}{B}\left[1 \pm \frac{6}{B}\cdot\frac{B}{6}\right]$$

or, $P_{max} = \frac{2W}{B}$ and $P_{min} = 0$

Hence, the maximum vertical stress equal to $\frac{2W}{B}$ will act at the heel and the vertical stress at toe will be zero.

When the reservoir is full, the base width is governed by:

(i) The resultant of all the forces i.e. P, W and U passes through the outer most middle third point (i.e. lower middle third point).

(ii) The dam is safe in sliding.

Construction of Galleries in Gravity dams

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Function and Types of Galleries in dams :-

(1) Foundation or Drainage Gallery :→

A gallery provided near the rock foundations, serves to drain off the water which percolates through the foundations. The gallery is called a foundation gallery or drainage gallery. Its size is usually varies from 1.5 m × 2.2 m to 1.8 m × 2.4 m.

(2) Inspection Galleries :→

Functions :-

(i) They intercept and drain off the water seeping through the dam body.

(ii) They provide access to drain interior for observing and controlling the behaviour of the dam.

(iii) They provide enough space for carrying pipes etc. during artificial cooling of concrete

(iv) They provide access for grouting and the concentration joints when this cannot be done from the face of the dam.

(3)

Design Criteria for Earth Dams :→

(1) A fill of sufficiently low permeability should be be developed out of the available materials, so as to best serve the intended purpose with minimum cost.
(2) Sufficient spillway and outlets capacities should be provided so as to avoid the possibility of overtopping during design flood.
(3) Sufficient freeboard must be provided for wind set-up, wave action, frost action and earthquake motions.
(4) The seepage line should remain well within the d/s face of the dam, so that no sloughing of the face occurs.
(5) There is little harm in seepage through a flood control dam.
(6) There should be no possibility of free flow of water from the u/s to the d/s face.
(7) The u/s face should be properly protected against wave action, and the d/s face against rains and waves upto tail water.
(8) The portion of the dam, d/s of the impervious core, should be properly drained by providing suitable horizontal filter drain, or toe drain or chimney drain etc.
(9) The u/s and d/s slopes should be so designed as to be stable under worst conditions of loading.
(10) The u/s and d/s slope should be flat enough, as to provide sufficient base width at the foundation level

Seepage Analysis:→ Pg. 799

The seepage through a pervious soil material, for two-dimensional flow, is given by Laplace equation.

$$\frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} = 0$$

where, $\phi = K \cdot h$ = Velocity potential

K = Permeability of the soil

h = Head causing flow.

The above equation is based on following assumptions:-

(i) Water is incompressible

(ii) The soil is incompressible and porous.

(iii) The quantity of water entering soil in any given time is the same as the quantity flowing out of soil.

(iv) Darcy's law is valid for the given soils

(v) The hydraulic boundary conditions at the entry and exit are known.

Pg. -801

Line of Seepage or Phreatic Line in Earth Dams

It is defined as the line within the dam section below which there are positive hydraulic pressures in the dam. The hydrostatic pressure on the phreatic line is equal to the atmospheric pressure and hence, equal to zero. Above the phreatic line, there is a zone of capillary saturation called capillary fringe in whic hydrostatic pressures are negative.

To determine absolutely essential position of the phreatic line, determine the following things:-

(i) It gives us a divide line between the dry and submerged soil.

(ii) It represents the top streamline and hence, helps us in drawing the flow net.
(iii) The seepage line determination, helps us to ensure that it does not cut the d/s face of the dam. This is extremely necessary for preventing softening or sloughing of the dam.

Piping :→
It is the progressive erosion and subsequent removal of the soil grains from within the body of the dam or the foundation of dam.

Sloughing :→
It is the progressive sive removal of soil from the wet d/s face. More than 1/3 rd of the earth dams have failed because of these reasons.

Seepage Control in Earth Dams :- Pg. 831 Diagram

(1) Through Embankments
Drainage filters called 'Drains' are generally provided in the form of (a) rock toe (b) horizontal blanket (c) chimney drain, etc. in order to control the seepage water. Filters reduces the pore pressures in the d/s portion of the dam and thus increases the stability of the dam, permitting steep slopes and thus affecting economy in construction.

(2) Through Foundations:-
The amout of water entering the pervious foundations, can be controlled by adopting following measures:

(a) Impervious Cutoffs:-
Vertical impervious cutoffs made of Concrete or sheet piles may be provided at the U/s end of the earthen dam. These cutoffs should generally extend through the entire depth of the pervious foundation so as to achieve effective control on the seeping water.

(b) Relief Wells and Drain Trenches:-
When large scale seepage takes place through the pervious foundation, overlain by a thin less pervious layer, there is a possibility that the water may boil up near the toe of the dam.

[*] Design of Filters:-> Pg.-834

The permeability or size of filter material should also be sufficient to carry the anticipated flow with an amole margin of safety. A rational approach to the design of filters has been provided by Terzaghi. According to him, the following filter criteria should be satisfied.

$$\frac{D_{15} \text{ of filter}}{D_{85} \text{ of base materials}} < 4 \text{ to } 5 < \frac{D_{15} \text{ of filters}}{D_{15} \text{ of base material}}$$

The embankment soil or the foundation soil surrounding the filter is known as base material.
When the ratio of D_{15} of filter to D_{85} of base material does not exceed 4 to 5, base material is prevented from passing through the pores of the filter.

Multilayered filters (3 layers) consisting of materials of increasing permeabilities from the bottom to top are, many a times, provided and are known as inverted filters. These are costly and should be avoided where possible.