

UNIT - 2Gravity Dam

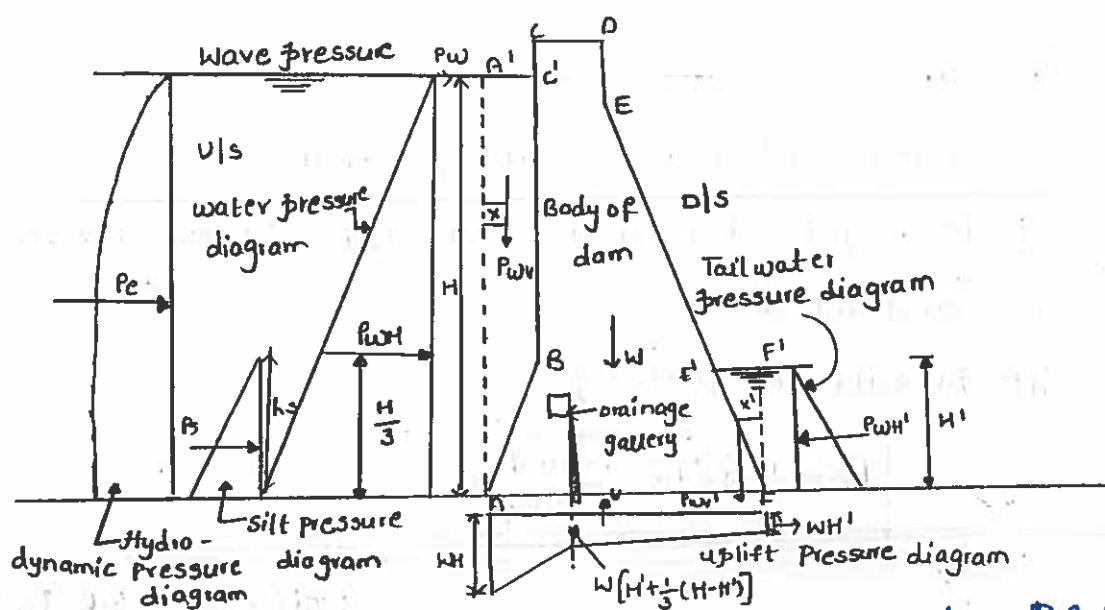
Def:

A gravity dam is a structure so proportioned that its own weight resists the forces exerted upon it. This type of dam is the most permanent one, but requires little maintenance. This type of dam is most commonly used. A gravity dam may be constructed either of masonry (or) concrete.

Forces acting on a gravity Dam

→ The following are the various forces acting on a gravity dam:

- a. Water pressure.
- b. Uplift pressure.
- c. Ice pressure.
- d. Silt pressure.
- e. Wave pressure.
- f. Wind pressure.
- g. Earthquake pressure.
- h. Weight of dam.



a. Water pressure

- i. This is the major external force acting on dam.
- ii. When the upstream face of the dam is vertical, the water pressure acts horizontally.
- iii. When the upstream face is partly vertical & partly inclined, the resultant water pressure can be resolved into two components.

$$\text{a. Horizontal component } [P_{WH}] = \frac{WH^2}{2}$$

$$\text{b. Vertical component } [P_{WV}]$$

b. Uplift pressure

- i. It is the pressure of the water which is acting on the body of the dam.
- ii. A portion of the weight of the dam will be supported on the upward pressure of water.

c. Ice pressure

- i. It is the most important for dams constructed in cold countries.
- ii. The ice formed on the water surface of the reservoir is subjected to expansion & contraction due to temperature variations.
- iii. This force acts linearly along the length of the dam, at the reservoir level.

d. Silt pressure

- i. The river brings silt & debris along with it.
- ii. The silt load gets deposited to an appreciable extent when dam is constructed.
- iii. The silt pressure is given by:

$$P_s = \frac{1}{2} g s' h_s^2 \frac{1 - \sin\phi}{1 + \sin\phi}$$

e. Wave pressure:

i. Waves are generated on the reservoir surface because of the wind blowing over it.

ii. Wave pressure depends on the height of the waves developed.

f. Wind pressure:

i. It is a minor force.

ii. It need hardly be taken into account for the design of dams.

iii. Wind pressure is required to be considered only on that portion of the super structure.

iv. Normally, wind pressure is taken as 1 to 1.5 kN/m^2 for the area exposed to the wind pressure.

g. Earthquake pressure

i. The earthquake sets up primary, secondary, Rayleigh & Love waves in the earth's crust.

ii. The waves impart accelerations to the foundations under the dam & causes its movement.

iii. Earthquake wave may travel in any direction.

h. Weight of the dam

i. It is major resisting force.

ii. For analysis purposes, generally, unit length of the dam is considered.

iii. The c/s of the dam may be divided into several triangles & rectangles.

iv. The total weight (w) of the dam acts at the C.G of its section.

Advantages/Merits of gravity dam:

i. Gravity dams are relatively more strong & stable than earth

dams :

- ii. Gravity dams are well adopted for use as an overflow spillway crest.
- iii. Gravity dams can be constructed of any height.
- iv. Gravity dam is specially suited to such areas where there is likelihood of very heavy downpour.
- v. It is most permanent type of dam.
- vi. Gravity dam requires the least maintenance.
- vii. The failure of gravity dam is not sudden.
- viii. It is cheaper.
- ix. It resists its own weight & forces exerted upon it.

Disadvantages / De-merits / Limitations of gravity dam:

- i. It can be constructed only on sound rock foundation.
- ii. The initial cost is high, compared with earth dam.
- iii. It takes more time to construct.
- iv. It required skilled labour.
- v. It is very difficult to allow subsequent rise in the height of a gravity dam.

Modes of failure : Stability Requirements

→ The following are the modes of failure of a gravity dam:-

- a. Over-turing failure.
- b. sliding failure .
- c. compression (or) crushing failure .
- d. Tension failure .

a. Overshooting Failure

- i. The overshooting of the dam section takes place when the resultant force at any section cuts the base of the dam downstream of the toe.
- ii. The factor of safety against overshooting is defined as the ratio of the ~~rigid~~ ^{stabilising} moment (+ve) to the overshooting moments.

i.e

$$F.S = \frac{\sum M_s / \text{stabilising moments}}{\sum M_o / \text{overturining moments}}$$

$$\therefore F.S = \frac{\sum M_s}{\sum M_o}$$

where,

$M_s \rightarrow$ stabilising moments

$M_o \rightarrow$ Overturining moments

- iii. The Factor of safety against overshooting should not be less than 1.5

b. sliding failure

- i. A dam will fail in sliding at its base.
- ii. The resistance against sliding may be due to friction.
- iii. The factor of safety against sliding is defined as the ratio of actual coefficient of static friction (μ) on the horizontal joint to the sliding friction.

$$F.S = \frac{\text{Actual coefficient of static friction}(\mu)}{\text{Horizontal joint to the sliding friction.}}$$

$$F.S = \frac{\mu \Sigma V}{\Sigma H}$$

iv. The F.O.S against sliding should be greater than 2.0.

c. compression (or) crushing failure

→ The total normal stress can be determined by the sum of the direct & bending stresses.

$$* \text{Direct stress} = \frac{V}{b}$$

$$* \text{Bending stress} = \pm \frac{6Vc}{b^2}$$

$$* \text{Total normal stress } (P_n) = \frac{V}{b} \left[1 \pm \frac{6c}{b} \right]$$

$$\rightarrow \text{Normal stress at the toe } [P_n]_{\text{toe}} = \frac{V}{b} \left[1 + \frac{6c}{b} \right]$$

$$\rightarrow \text{Normal stress at the heel } [P_n]_{\text{heel}} = \frac{V}{b} \left[1 - \frac{6c}{b} \right]$$

→ The maximum compressive stress to occur at the toe, the above equation should be less than (or) equal to the allowable compressive stress "f"

$$\boxed{\frac{V}{b} \left[1 + \frac{6c}{b} \right] \leq f}$$

d. Tension failure

i. This failure may occurs when the resultant strikes the middle third portion.

ii. To avoid failure due to tension, the resultant should always lie within the middle third portion.

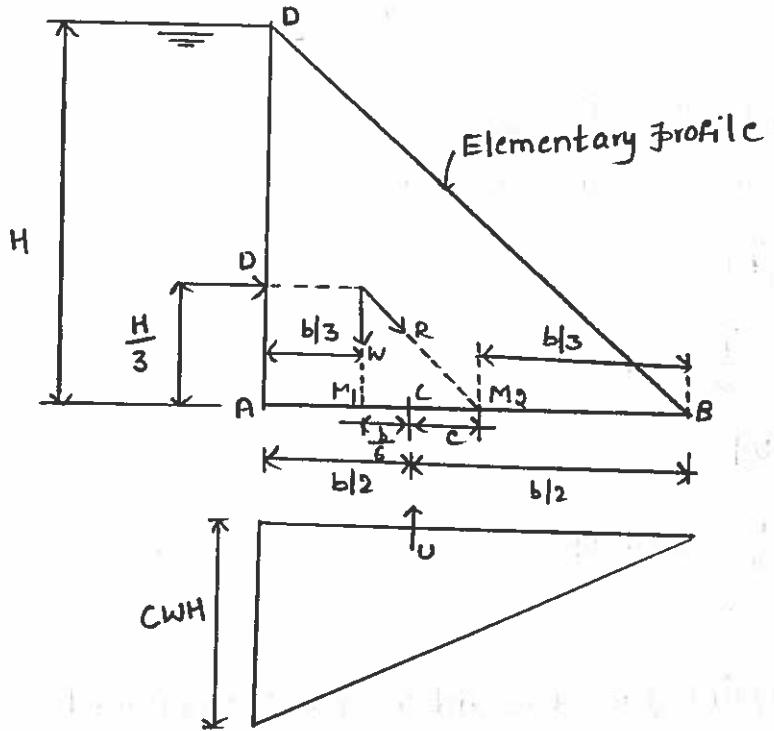
→ The tension (or) normal stress at the heel:-

$$[P_n]_{\text{heel}} = \frac{V}{b} \left[1 - \frac{6c}{b} \right]$$

→ For no-tension to develop, 'c' should be lesser than $\frac{b}{6}$ so that the normal stress at the heel would be negative.

Elementary profile & practical profile of a gravity dam

a. Elementary profile of a gravity Dam :-



* Elementary profile of a gravity dam *

- Consider an elementary profile to be triangular in section with zero width at the water level [i.e. water pressure is zero] & maximum width at the base [i.e. water pressure is maximum]
- The section of an elementary profile is quite similar to the shape of hydrostatic pressure distribution diagram.
- The following forces acting on the elementary profile of a gravity dam :

- i. Weight of the dam [W]
- ii. Water pressure [P]
- iii. uplift pressure [U]

i. Weight of the dam (W) :

$$W = \frac{1}{2} b H \cdot f w$$

where,

$f \rightarrow$ specific gravity of dam material.

$w \rightarrow$ unit weight of water.

ii. Water pressure (P)

$$P = \frac{1}{2} w H^2$$

iii. Uplift pressure (U)

$$U = \frac{1}{2} c \cdot w \cdot b \cdot H$$

Where,

$c \rightarrow$ uplift pressure intensity coefficient.

Base width of elementary profile

The base width of the elementary profile is to be found under two criteria:

a. Stress criterion

b. stability (or) sliding criterion.

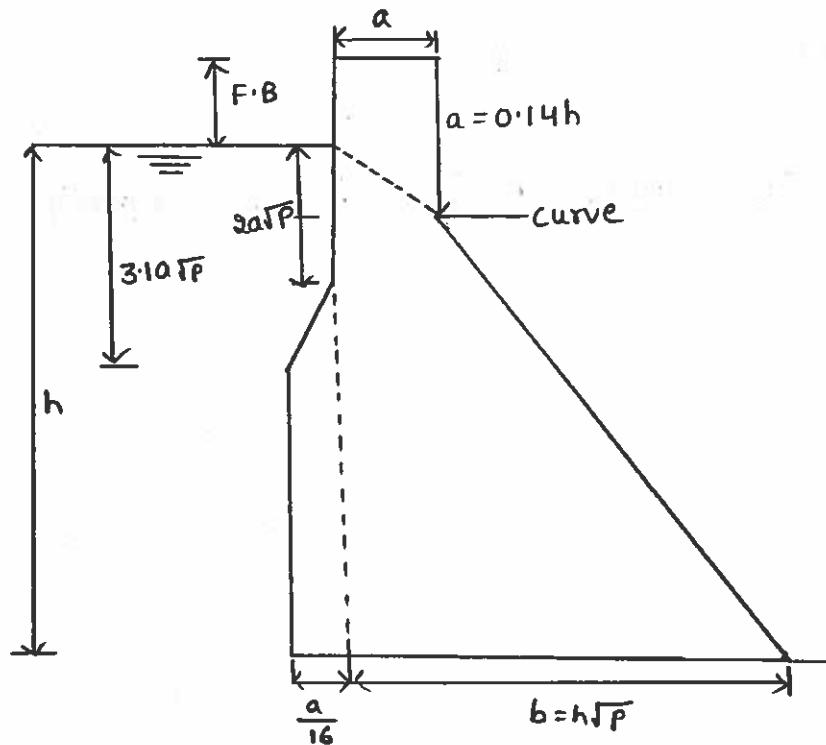
Stresses developed in the elementary profile:

a. Normal stress.

b. Principal stress at the toe.

c. Shear stress at the toe.

b. practical profile of a gravity Dam :-



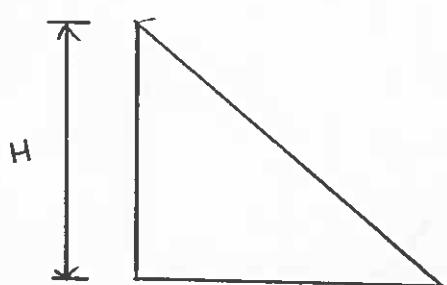
* Practical profile of a gravity dam *

- The elementary profile of the gravity dam is only a theoretical profile.
- However, such a profile is not possible in practise because of the provision of :
 - i. Roadway at the top.
 - ii. Additional loads due to the roadway.
 - iii. Free board.
- Due to these provisions, the resultant force of the weight of the dam & the water pressure falls outside the middle third of the base of the dam when the reservoir is full.
- To eliminate tension, some masonry is to be provided to the upstream side.

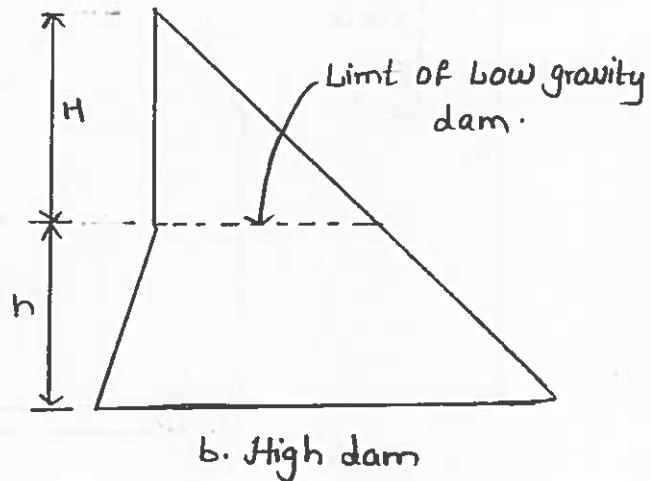
Free board:

$$\text{Free board} = \frac{4}{3} hw + \text{wind set-up}$$

Limiting height of a gravity dam: High & Low Gravity dams



a. Low dam



b. High dam

→ The principal stress at the toe is given by:-

$$\sigma_t = \omega H [f - c + 1]$$

→ In this expression the only variable, changing the value of σ_t is H , The maximum value of this principal stress should not exceed the allowable stress (f) for the material.

$$f = \sigma_t = \omega H [f - c + 1]$$

→ From the above equation, the height [H] is :-

$$H = \frac{f}{\omega(f - c + 1)} \rightarrow ①$$

NOW, put $c=0$, we get

$$H = \frac{f}{\omega(f + 1)} \rightarrow ②$$

→ The maximum compressive stress will exceed the permissible stress.

- The limiting height defines the distinction between a low & high gravity dam.
- A low gravity dam is the one in which the height (H) is less than the eq(2), so that maximum compressive stress is not greater than the allowable stress.
- A high gravity dam is the one in which the height (H) is more than the eq(2), so that the compressive stress within the limit.

Factor of Safety - Stability Analysis, Foundation for a Gravity Dam

Factor of safety

"Factor of safety" is also known as "safety factor", is a term describing the load carrying capability of a system beyond the expected (or) actual loads.

Stability Analysis:

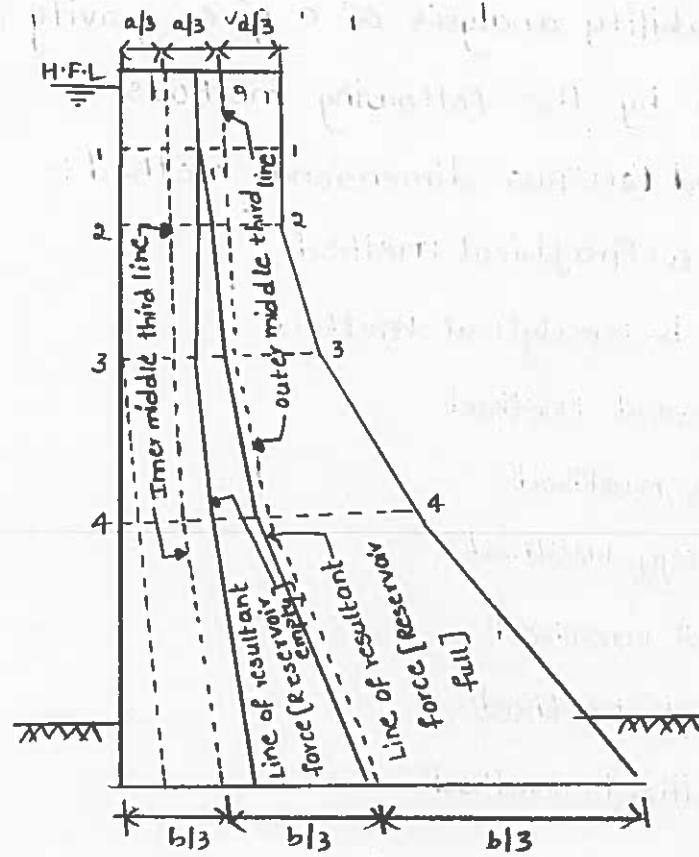
The stability analysis of a given gravity dam section may be carried out by the following methods:-

- i. Gravity method (or) Two-dimensional method :-
 - a. Graphical Method
 - b. Analytical Method.
- ii. Trial load twist method.
- iii. Slab analogy method.
- iv. Lattice analogy method.
- v. Experimental method :-
 - a. Direct method.
 - b. Indirect method.

i. Gravity Method (or) Two-Dimensional Method:

- This is an approximate method in which the dam is considered to be composed of parallel sided vertical cantilevers.
- The loads (or) forces are resisted entirely by the self weight of the gravity dam.
- This method is easy & accurate.
- Other methods of design & analysis are complicated & time consuming.
- Hence, preliminary calculations are always done with the help of this method.
- It consists of two methods:
 - a. Graphical method.
 - b. Analytical method.

a. Graphical Method



- In this method, the dam section is divided into horizontal section 1-1, 2-2, 3-3 etc.
- At some suitable interval (or) at the places where slope changes
- For each section, the sum of all horizontal forces (ΣH) & the sum of all vertical forces (ΣV) are calculated by this method.
- This procedure is adopted for both conditions :-
 - i. Reservoir full condition.
 - ii. Reservoir empty condition.

b. Analytical Method

The stability analysis by the analytical method is done in the following steps:

- i. consider unit length of the dam. calculate all the vertical loads acting. Find the algebraic sum of vertical forces (ΣV)
- ii. Find out the sum of horizontal forces (ΣH) & the horizontal pressure due to hydrodynamic pressure.
- iii. Find out the sum of the over turning moments (ΣM_O) by :-

$$\Sigma M = \Sigma M_R - \Sigma M_O$$

- iv. Find out the location of the resultant forces (R) from toe, by :-

$$\bar{x} = \frac{\Sigma M}{\Sigma V}$$

- v. Find out the eccentricity (e) of the resultant (R) from the centre by :-

$$e = \frac{b}{2} - \bar{x}$$

- vi. Find the normal stress at :

$$a. \text{ Toe of dam : } P_n = \frac{\Sigma V}{b} \left[1 + \frac{6e}{b} \right]$$

$$b \cdot \text{Heel of dam} :- P_n = \frac{\Sigma v}{b} \left[1 - \frac{6e}{b} \right]$$

vii. Find out the principal & shear stresses at the toe & heel.

viii. Find out the factor of safety against Overturning by :-

$$F.S = \frac{\Sigma M_R}{\Sigma M_O}$$

ix. Find out the factor of safety against sliding by :-

a. Sliding factor :- $S.F = \frac{\mu \Sigma V}{\Sigma H}$

b. Shear friction factor : $S.F = \frac{\mu \Sigma V + b c}{\Sigma H}$

c. Factor of Safety against sliding :

$$F = \frac{\frac{\mu \Sigma V}{F_\phi} + \frac{c b}{F_c}}{\Sigma H}$$

Foundation for a gravity dam :

The material under lying the base of a dam, the foundation of the dam must be strong enough & capable to withstand the foundation pressure, exerted on it under various conditions of loading. Most of the failures of the dam have occurred because of failure of their underlying state.

Foundation treatment

The foundation treatment commonly adopted for all the foundations can be divided into 2 steps :-

a. preparing the surface.

b. Grouting the foundation.

i. Consolidation grouting.

ii. curtain grouting.

a. Preparing the surface

i. Remove the entire loose soil till a sound bed rock is exposed.

ii. The excavation should be carried out, in such a way that the underlying rock is not be damaged.

iii. If faults & folds are occurred in rock zone, then special steps & remedies should be done.

b. Grouting the foundation:

The foundation grouting can be divided into 2 subdivisions.

i. consolidation grouting.

ii. curtain grouting.

Galleries

Def:

A gallery is small Passage in dams to provide a path to the interior of the dam for inspection & maintenance. It is used in dams for various purposes such as grouting, drainage, housing, pumping, control of gates & other equipments etc.

Types of Galleries

Galleries are broadly classified into five types:

a. Drainage gallery.

b. Inspection gallery.

c. Foundation gallery.

- d. Gate gallery.
- e. Grouting gallery.

a. Drainage gallery

- It may be attached to the foundation (or) It may be separately provided depending upon the size of the dam.
- If the dam is high then it requires a supplementary drainage gallery.
- It is located at a distance of $\frac{2}{3}$ rd of base width measured from upstream.
- It is usually provided in the deepest portion of dam.
- Drainage holes are drilled into the foundation for the drain purpose.

b. Inspection gallery:

- It is used for inspection of dam through the passages provided by the gallery.
- It is also used for recording & analysing the observations of various instruments & devices installed in the dam.
- In small dams, no separate inspection gallery is provided.
- But, in large dams, separate inspection gallery is provided.

Purposes/uses of galleries

- Following are the purposes for which a gallery is formed in the dams:-
 - i. To provide drainage of the dam section.
 - ii. To provide facilities for drilling & grouting operations for foundations.
 - iii. To provide space for header & return pipes.

iv. To provide access to observe & measure the behaviour of the structure.

v. To provide access of mechanical contrivances.

Shapes of galleries:-

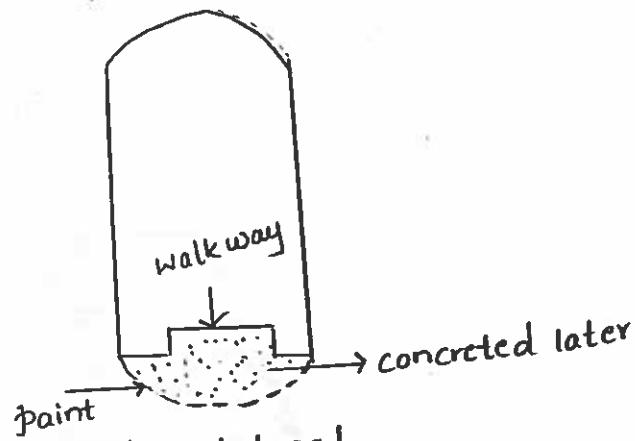
→ Two types:

a. Rectangular shaped.

b. Oval shaped.

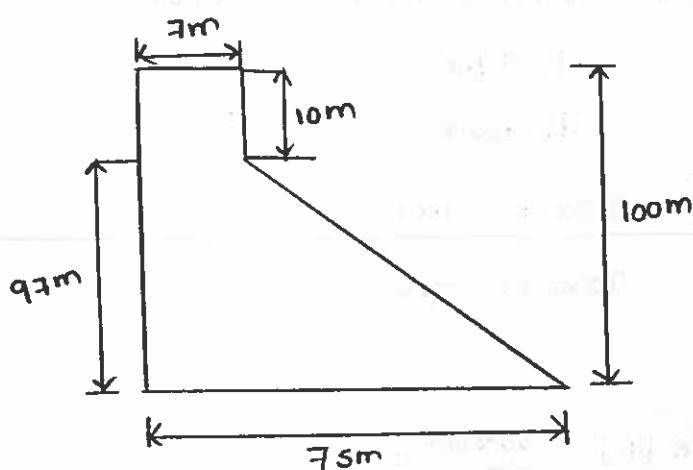


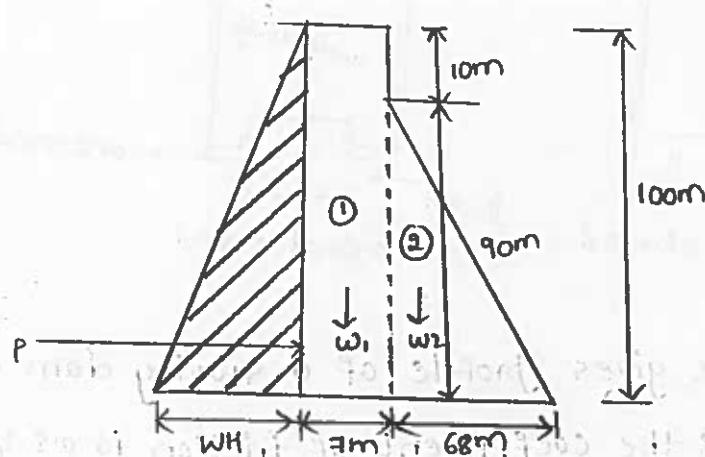
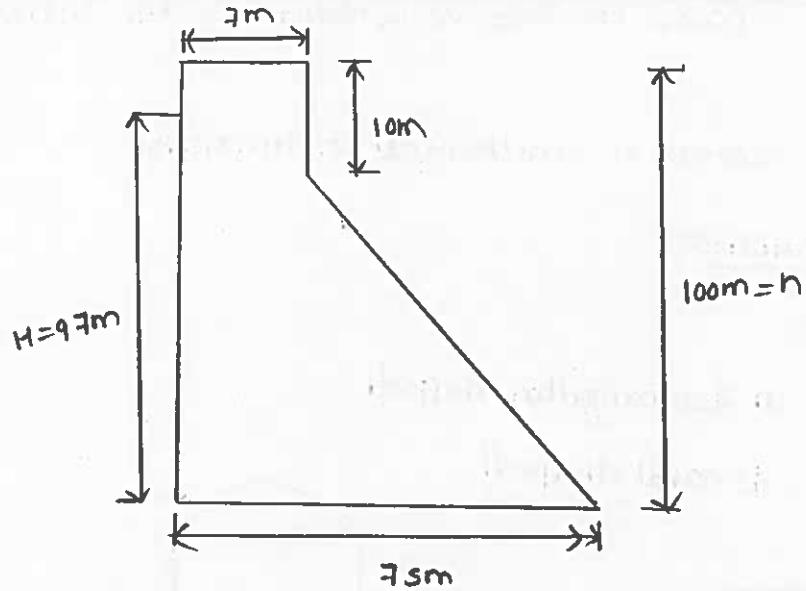
a. Rectangular shaped



b. Oval shaped.

1. The following figure gives profile of a gravity dam with reservoir level as shown. If the coefficient of friction is 0.8 & weight density of concrete is 2.4 t/m^3 , check the safety of the dam against sliding & Overturning. Assume any other data if not given.





Given data:

$$\text{Coefficient of friction } (\mu) = 0.8$$

$$\text{Weight density of concrete} = 2.4 \text{ t/m}^3$$

$$H = 9.7 \text{ m}$$

$$h = 100 \text{ m}$$

$$\text{Area (A)} = 7 \text{ m}$$

$$\text{Take (W)} = 1000$$

Calculation

$$\rightarrow \text{Water pressure } [P] = \frac{W \times H^2}{2 \times 1000}$$

$$= \frac{1000 \times (9.81)^2}{2000}$$

2000

$$P = 4704.5 \text{ tonnes/m}$$

→ Self weight of section [1]

$$W_1 = \text{Area} \times \text{Weight density} \quad (\because \text{Area} = 1 \times b)$$

$$= 7 \times 100 \times 2.4$$

$$W_1 = 1680 \text{ t/m}$$

→ Self weight of section [2]

$$W_2 = \frac{1}{2} \times 68 \times 90 \times 2.4 \text{ [weight density]}$$

$$W_2 = 7344 \text{ t/m}$$

$$\therefore \text{Total self weight of concrete } [W] = W_1 + W_2$$

$$W = 1680 + 7344$$

$$W = 9024 \text{ t/m}$$

∴ Factor of safety against sliding is given by :-

$$F_{\text{safety}} = \frac{\mu \times W}{P}$$
$$= \frac{0.8 \times 9024}{4704.5}$$

$$F_{\text{safety}} = 1.534 > 1$$

∴ The value of factor of safety against sliding is greater than 1 & hence the dam is safe against sliding.

Moment due to self weight of dam :-

$$M_w = \left[(7 \times 100 \times 2.4) (68 + 3.5) \right] + \left[\left(\frac{1}{3} \times 90 \times 68 \times 2.4 \right) \left(\frac{2}{3} \times 68 \right) \right]$$

$$M_w = 453048 \text{ t/m}$$

Moment due to uplift force

$$M_{up} = \frac{1}{2} \times 75 \times 1 \times 100 \times \frac{2}{3} \times 75$$

$$M_{up} = 187500$$

Moment due to horizontal water pressure

$$M_{hwp} = 4704.5 \times \frac{97}{3}$$

$$M_{hwp} = 152112.1667$$

Oversetting Moment :

$$\Sigma M_{ov} = M_w$$

$$\Sigma M_{ov} = 453048$$

Resisting Moment

$$\Sigma M_{re} = M_{up} + M_{hwp}$$

$$= 187500 + 152112.1667$$

$$\Sigma M_{re} = 339612.1667$$

\therefore Factor of safety against oversetting is given by:-

$$F_{ov} = \frac{\Sigma M_{ov}}{\Sigma M_{re}}$$

$$= \frac{453048}{339612.1667}$$

$$F_{ov} = 1.334 < 1.5$$

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∴ The value of factor of safety against overturning is less than 1.5 & hence dam is unsafe against overturning.

→ Factor of safety against sliding

$$F_s = \frac{\mu \times w}{f}$$

→ Factor of safety against overturning

$$F_{ov} = \frac{\sum M_{ov}}{\sum M_{re}}$$

