LECTURE # 5

Analysis And Design of Gravity Dam

In this lecture you will learn about:

- Gravity Dam.
- Parts of Gravity Dam.
- Forces on Gravity Dam.
- Numerical (F-O-G-D)
- Design of Gravity Dam
- Steps
- Steps of Procedure For Design of Gravity Dam

Course Name

"Irrigation And Hydraulic Structures"

Course Code: CT-351

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Analysis And Design of Gravity Dam

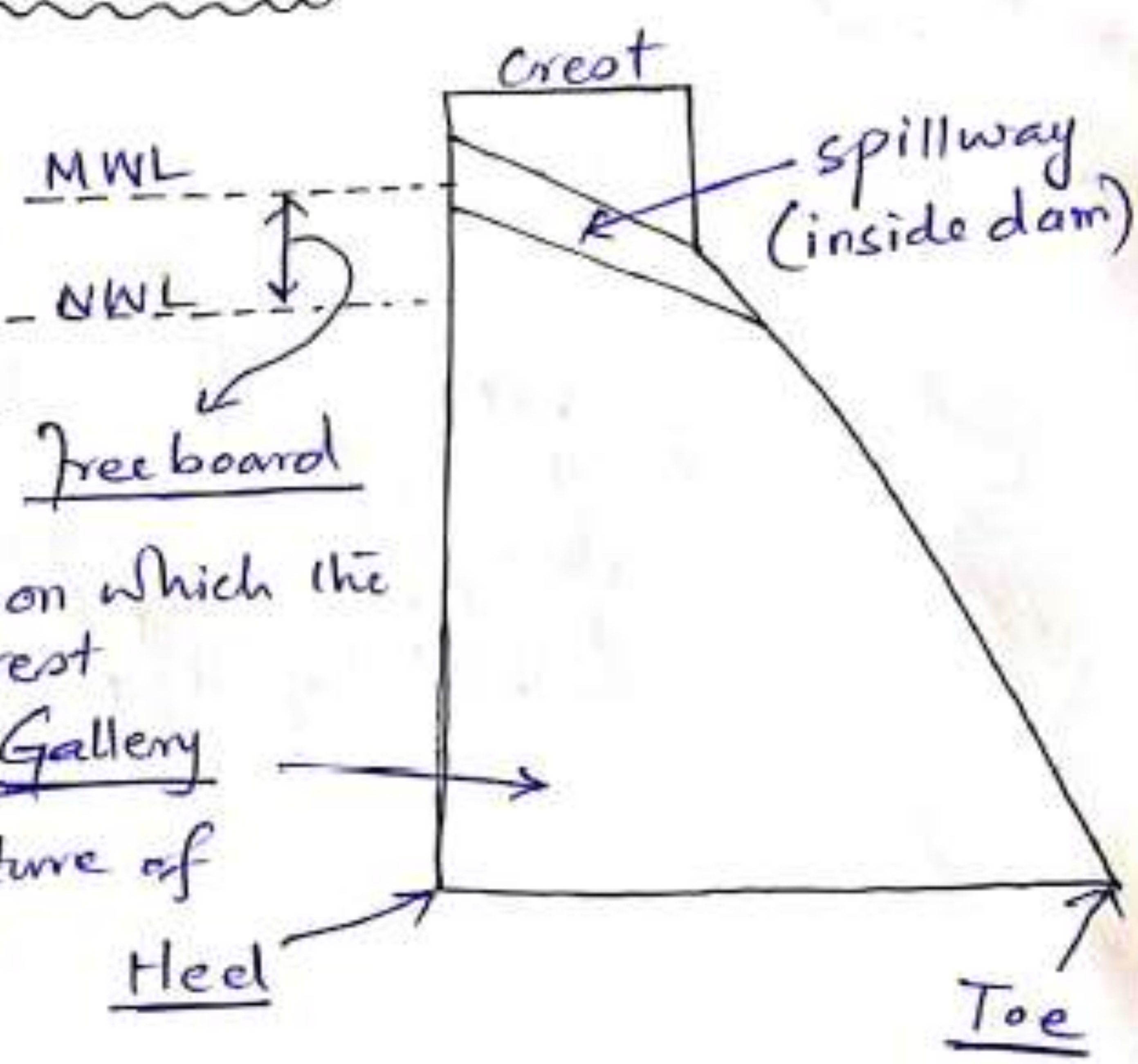
Gravity Dam:-

"A structure which is designed in such away that its own weight resist the external forces"

This type of a structure is most durable and solid and requires very less maintainance.

* Such dams are Constructed of masonry or Concrete.
* Now a days gravity dams are mostly preferred and mostly constructed.

Structure (Parts) of Gravity Dams:-



Heel contact with the ground on the upstream Side

Toe:- Contact on the down-stream side

Abutment:- Sides of the valley on which the structure of the dam rest

Gallaries:- Small room like structure of the dam, for checking operation.

Spillways:- It is the arrangement near the top to release the excess of water of the reservoir to D/s side

Forces on Dams:-

In the design of a dam, the first step is the determination of various forces which acts on the structure and study their nature. Depending upon the situation, the dam is subjected to the following forces:-

(1) — Water pressure
(2) — Earth Quake pressure
(3) — Silt pressure.
(4) — Wave pressure
(5) — Ice pressure.
(6) — Self weight of the dam.

The forces are considered to act per unit length of the Dam.

For perfect and most accurate design, the effect of all the forces should be investigated out of these forces, most common and important forces are water pressure and self weight of the Dam.

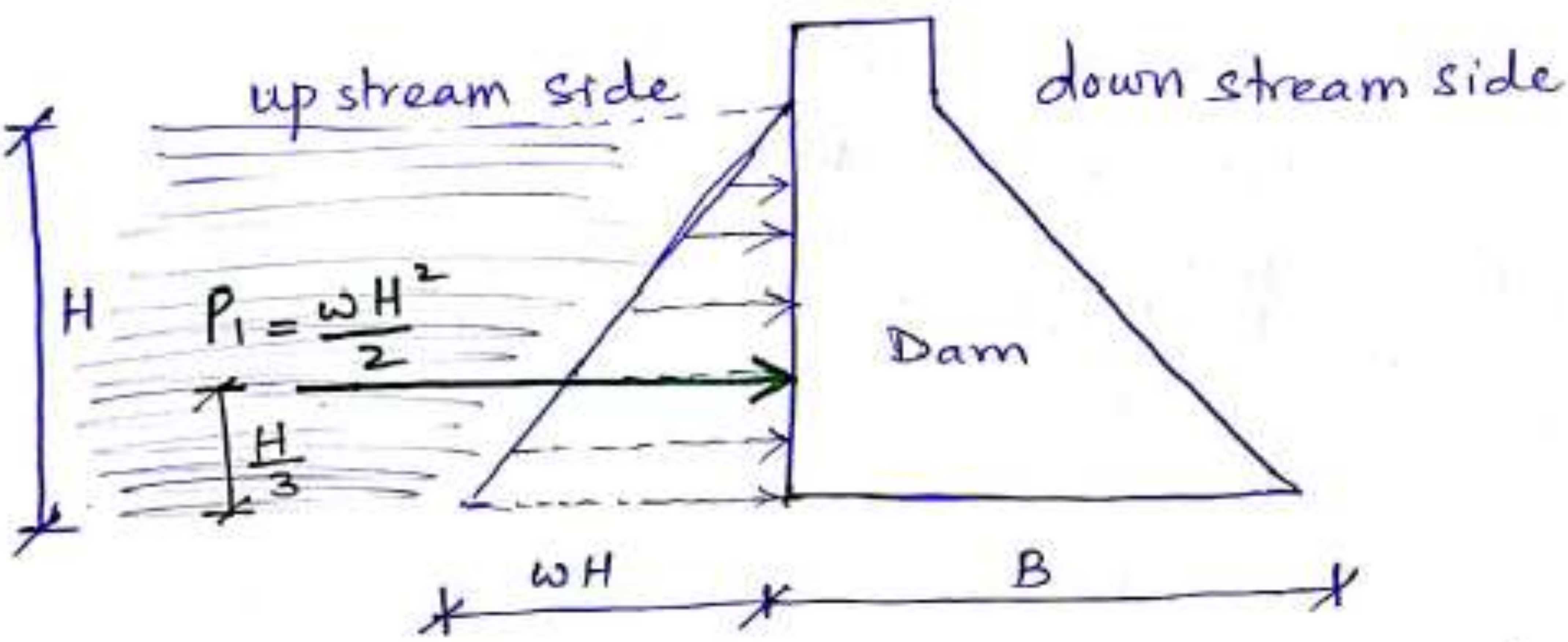
(1) Water Pressure:-

Water pressure may be subdivided into the following two categories:-

External water pressure:-

It is the pressure of water on the upstream face of the Dam. In this, there are two cases:-

(i) Upstream face of the Dam is vertical and there is no water on the downstream side of the dam



The total pressure is in horizontal direction and acts on the upstream face at a height $\frac{H}{3}$ from the bottom. The pressure diagram is triangular and the total pressure is given by;

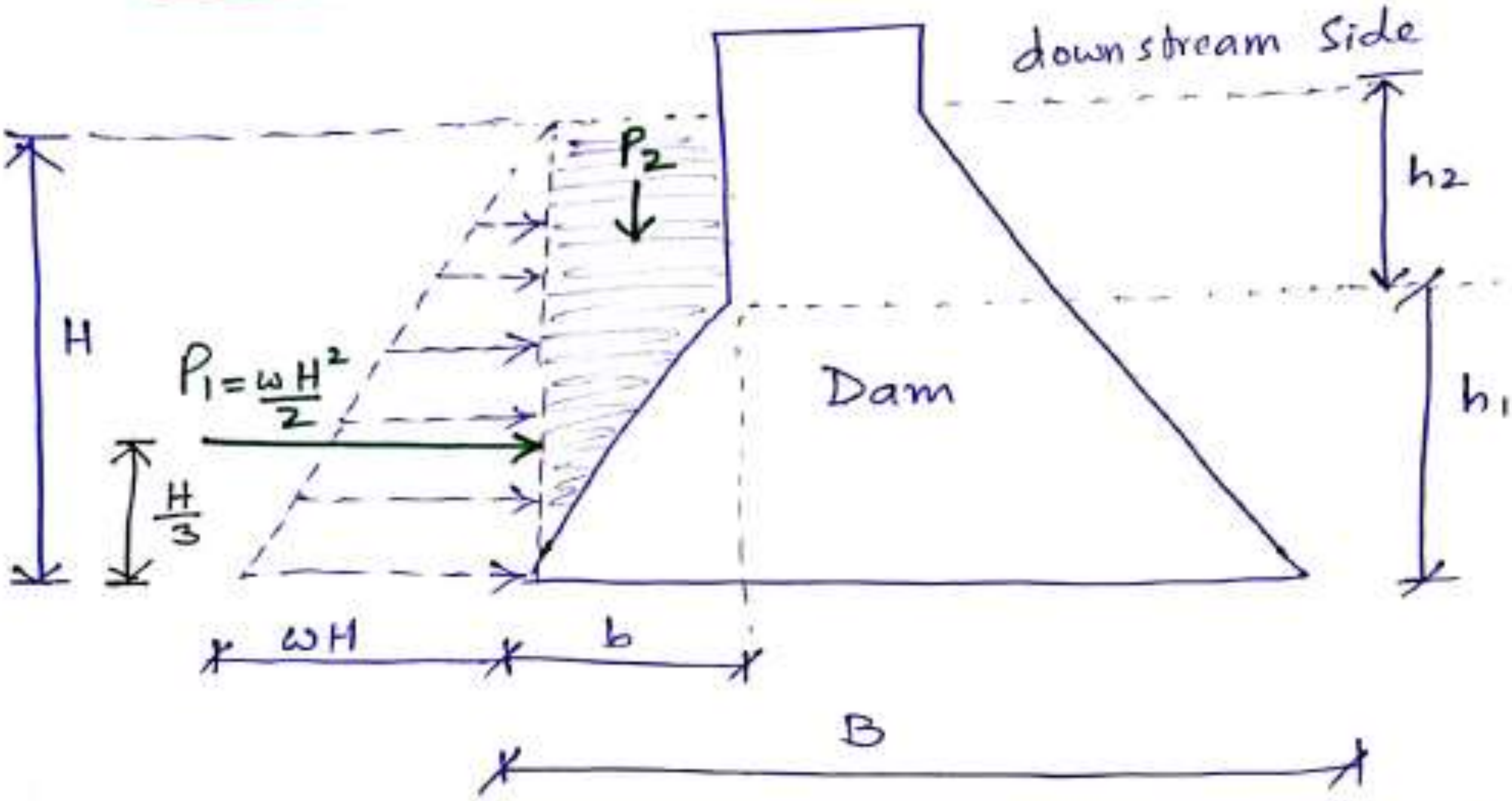
$$P_1 = \frac{wH^2}{2}$$

Where;

w = specific weight of water. usually taken as unity.

H = Height of water in the reservior. (Stored water).

(ii) upstream face with batter and there is no water on the down stream side



Here in addition to the horizontal water pressure P_1 as in the previous case, their is vertical pressure of the water.

It is due to the water column resting on the upstream slopping side.

The vertical pressure P_2 acts on the length "b" portion of the base. The vertical pressure is given by.

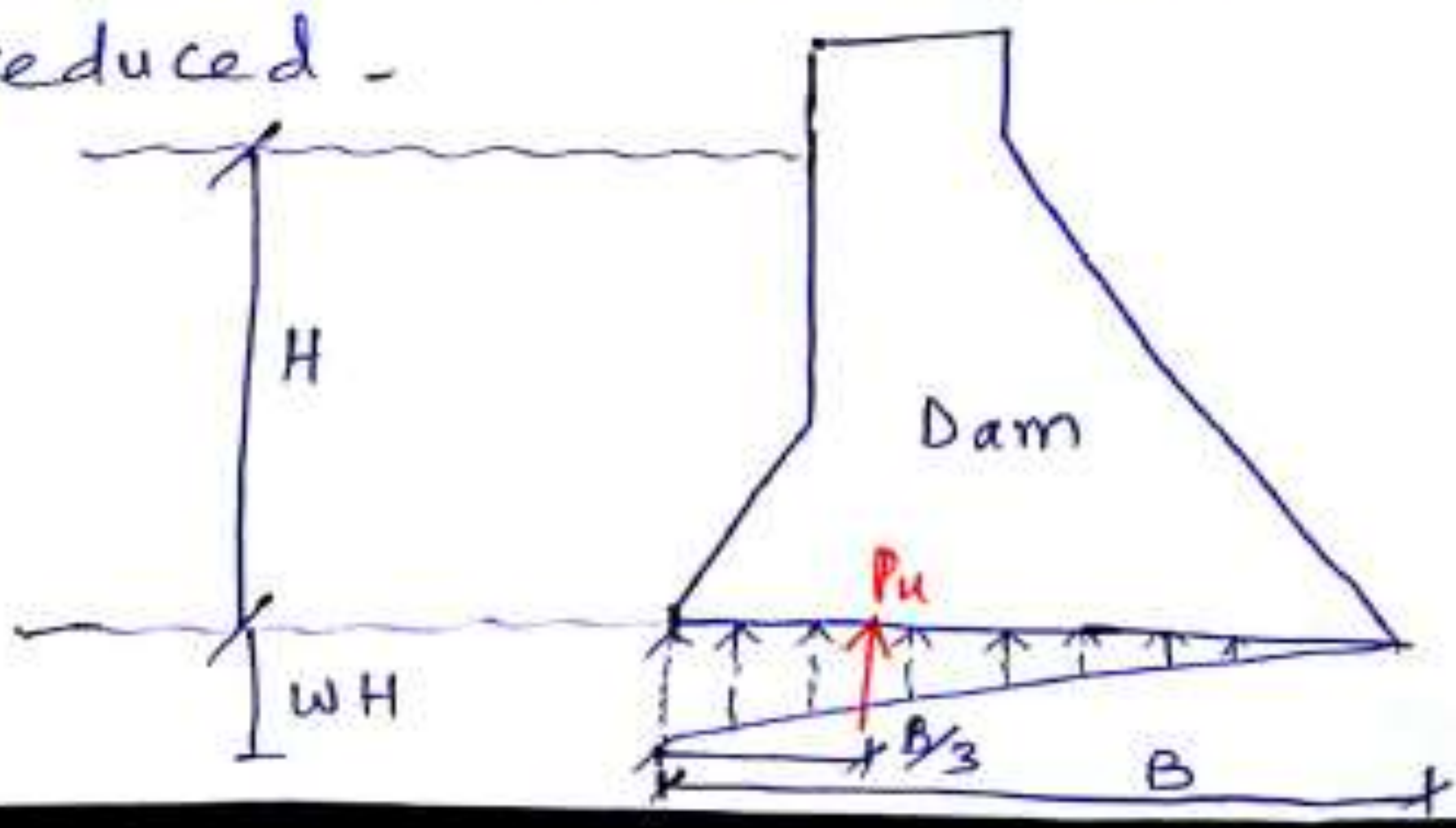
$$P_2 = (b \times h_2 \times \omega) + \left(\frac{1}{2} b \times h_1 \times \omega\right)$$

Pressure "P_2" acts through the centre of gravity of the water column restrig on the slopping upstream face.

Water Pressure below the base of the Dam or uplift pressure :-

When the water is stored on the upstream side of a dam there exists a head of water. The water enters the pores of the foundation material under pressure.
It also enters the joint between the dam and foundation at the base and the pores of the dam itself.

This water then seeps through and tries to emerge out on the down stream end.
The water seeped creates hydraulic gradient b/w upstream and down stream side of the dam.
This hydraulic gradient causes vertical upward pressure. The upward pressure is known as uplift. uplift reduces the effective weight of the structure and hence restoring force is reduced.



uplift pressure is given by

$$P_u = \frac{\omega H \times B}{2}$$

Where;

P_u = uplift pressure

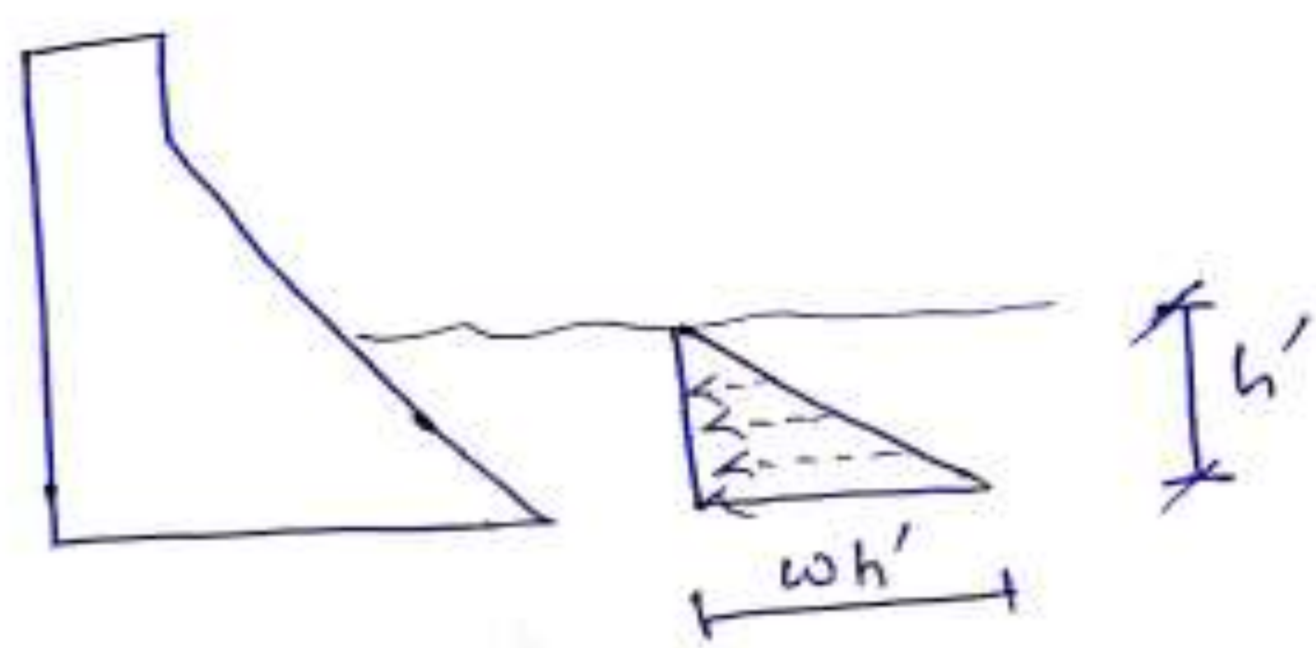
B = Base width of the Dam.

H = Height upto which water is Stored.

This total uplift acts as $\frac{B}{3}$ from the heel or upstream end of the Dam.

Tail water Pressure:-

It also acts in horizontal direction towards upstream side;



$$P_{wt} = \frac{1}{2}\omega h' \times h'$$

$$\boxed{P_{wt} = \frac{1}{2}\omega h'^2}$$

(2) Earthquake Forces :-

* The effect of earthquake is equivalent to an acceleration to the foundation of the dam in the direction in which the wave is travelling.

* Earth quake wave may move in any direction and for design purpose, it is resolved into the vertical and horizontal directions.

* On an average, a value of 0.1 to 0.15g is generally sufficient for high dams in Seismic zones. In extremely seismic zone regions even a value of 0.3 g may sometimes be adopted.

$$F_{va} = K_v \times W$$

$M_e = 0.299 P_{hdf} h^2$

$P_{hdf} = 0.725 P_{hdp} h$

$P_{hdp} = c_y h K \gamma_w$

(3) Silt Pressure :-

If h is the height of silt deposited, then the forces extented by the silt can be represented by Rankine Formula.

$$P_{silt} = \frac{1}{2} \gamma_s h^2 K_a$$ acting at $\frac{h}{3}$ from the base.

Where;

K_a = Coefficient of active earth pressure of silt

$$K_a = \frac{1 - \sin\phi}{1 + \sin\phi}$$

ϕ = angle of internal friction of soil

γ_s = Submerged unit weight of silt material.

h = height of silt deposited.

(4) Wave Pressure:-

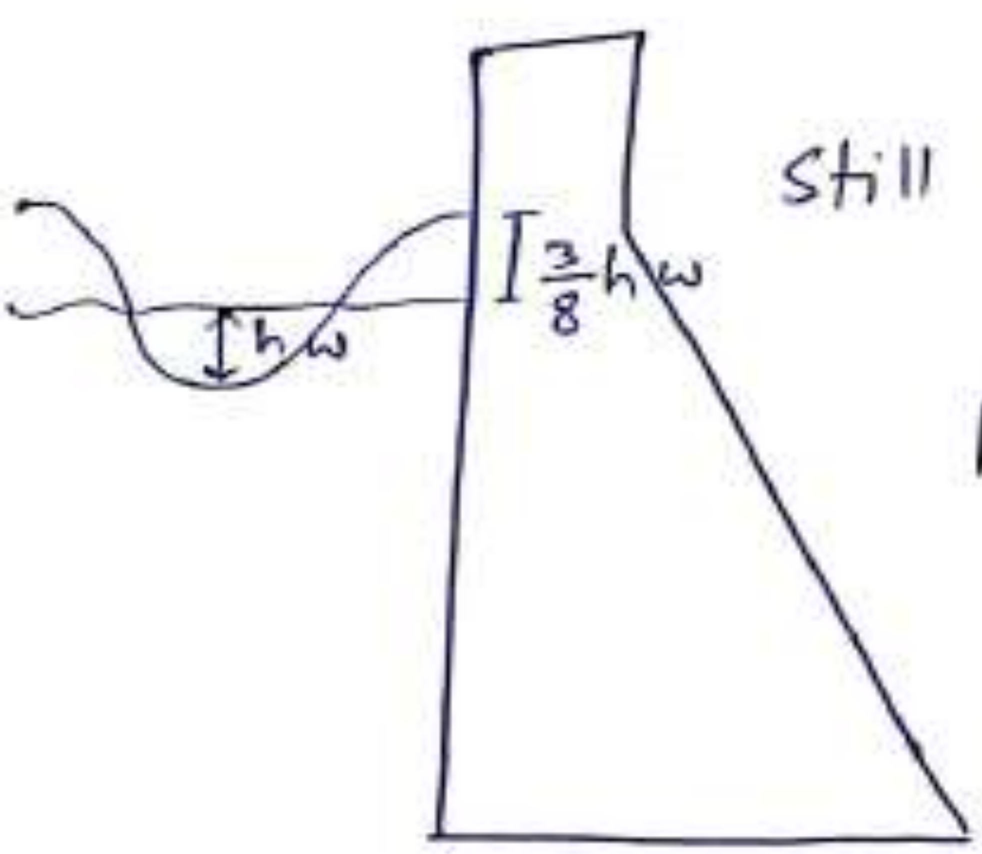
Waves are generated on the surface of the reservoir by the blowing winds, which exerts pressure.

Wave pressure depends upon wave height which is given by the equation.

$$h_w = 0.032\sqrt{FV} + 0.763 - 0.271 \times (F)^{\frac{1}{4}}$$

for $F < 32$ km

$$h_w = 0.032\sqrt{VF} \quad \text{for } F > 32 \text{ km}.$$



h_w is depth of water from still water to the trough.

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

acting at $\frac{3}{8}$ above the reservoir surface.

(5) Ice Pressure:-

* The ice which may be formed on the water surface of the reservoir in cold countries. This exerts pressure on the dam. This force acts linearly along the length of the Dam.
* The magnitude of the force varies from 250 to 1500 KN/m^2 depending upon temperature variations. On an average, a value of $500 \frac{KN}{m^2}$ may be taken under ordinary circumstances.

(6) Weight of Dam:-

* The weight of the Dam is the main stabilizing force.
* The Dead Load to be considered weight of concrete or masonry of the dam section plus the weight of gates etc.

However in small Dams only Dead Load of concrete or masonry is taken.

The Weight of the Dam section per unit length is given by

$$W = \gamma V$$

$$W = \gamma A L \qquad L = 1\,m.$$

$$\boxed{W = \gamma A}$$

γ = Unit weight of Dam Material
A = Area of Dam Section.

Example :-

An elementary profile of Dam is Subject to Earthquake forces (both horizontal and vertical) uplift pressure and hydrostatic pressure. Determine the base width of the Elementry profile so that there is no tension and no sliding use the following Datas

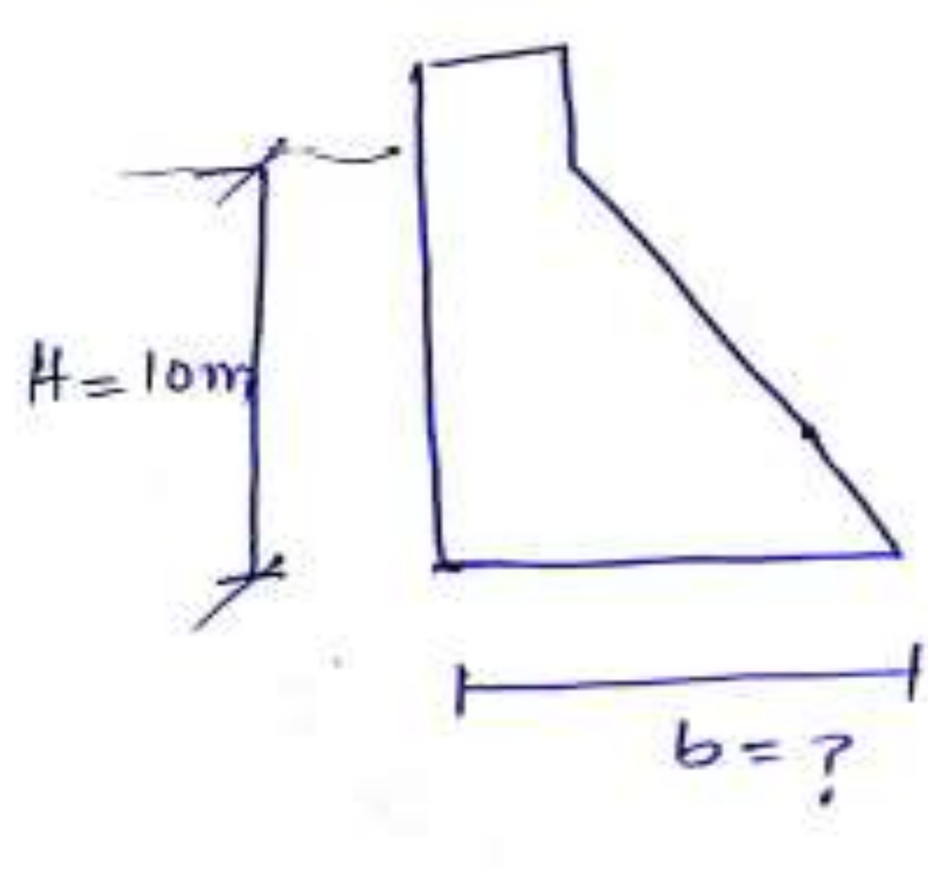
Depth of water in the Reservoir = 10m
Specific Gravity of Dam Material = 2.4 = G
Earth quake pressure in horizontal and vertical direction = 0.1g = $K_v g$ = $K_h g$ $K_v = K_h = 0.1$

$\mu = 0.8$

unit weight of water = γ_w = 1000 Kg/m³

Also find base width of Dam if no Earth quake is present.

Solution:-



① $\gamma_m = G\,\gamma_w$

$\gamma_m = 2.4 \times 1000$

$$\boxed{\gamma_m = 2400\ kg/m^3}$$

(2) Wt of the Dam $= \frac{1}{2} A \gamma_m$

$$W = \frac{1}{2} \times bh\gamma_m$$

$$W = \frac{1}{2} b \times 10 \times 2400$$

$$\boxed{W = 12000b}$$

(3) Force due to vertical Acceleration (EQ)

$$F_{va} = K_v \times W$$

$$F_{va} = 0.1 \times 12000b$$

$$\boxed{F_{va} = 1200b}$$

(4) uplift pressure (Vertical) $= P_{up} = \frac{1}{2} \gamma_w bh$

$$P_{up} = \frac{1}{2} \times 1000 \times b \times 10$$

$$\boxed{P_{up} = 5000b}$$

$$\Sigma V = W - F_{va} - P_{up} \quad ; \downarrow^{+} \quad \overset{+}{\uparrow}$$

$$\Sigma V = 12000b - 1200b - 5000b$$

$\boxed{\Sigma V = 5800b}$ Sum of vertical forces.

(5) pressure due to water (Horizontal) $= P_w = \frac{1}{2} \gamma_w H^2$

$$P_w = \frac{1}{2} \times 1000 \times 10^2$$

$$\boxed{P_w = 50000 \text{ kg}}$$

(6) Hydro dynamic Force "P_{hdF}"

$$P_{hdF} = 0.725\, P_{hdp} * h \rightarrow (1)$$

Hydro dynamic Pressure "P_{hdp}"

$$P_{hdp} = c_y\, h\, K_h\, \gamma_w$$

$$P_{hdp} = 0.735 \times 10 \times 0.1 \times 1000$$

$$\boxed{P_{hdp} = 735 \text{ Kg}}$$

Now using $P_{hdF} = 0.725\, P_{hdp}\, h$

$$P_{hdF} = 0.725 \times 735 \times 10$$

$$\boxed{P_{hdF} = 5328.75 \text{ Kg}}$$

Moment due to hydrodynamic force

$$M_e = 0.299\, P_{hdF}\, h^2$$

$$M_e = 0.299 \times 5328.75 \times 10^2$$

$$\boxed{M_e = 21976.5 \text{ Kg-m}}$$

Horizontal Force (due to inertia) = $F_i = K_h W$

$$F_i = 0.1 \times 120006$$

$$\boxed{F_i = 12006}$$

(6) Hydro dynamic Force "P_{hdF}"

$$P_{hdF} = 0.725 P_{hdp} * h \rightarrow (1)$$

Hydro dynamic Pressure "P_{hdp}"

$$P_{hdp} = c_y h K_h \gamma_w$$

$$P_{hdp} = 0.735 \times 10 \times 0.1 \times 1000$$

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Now using $P_{hdF} = 0.725 P_{hdp} h$

$$P_{hdF} = 0.725 \times 735 \times 10$$

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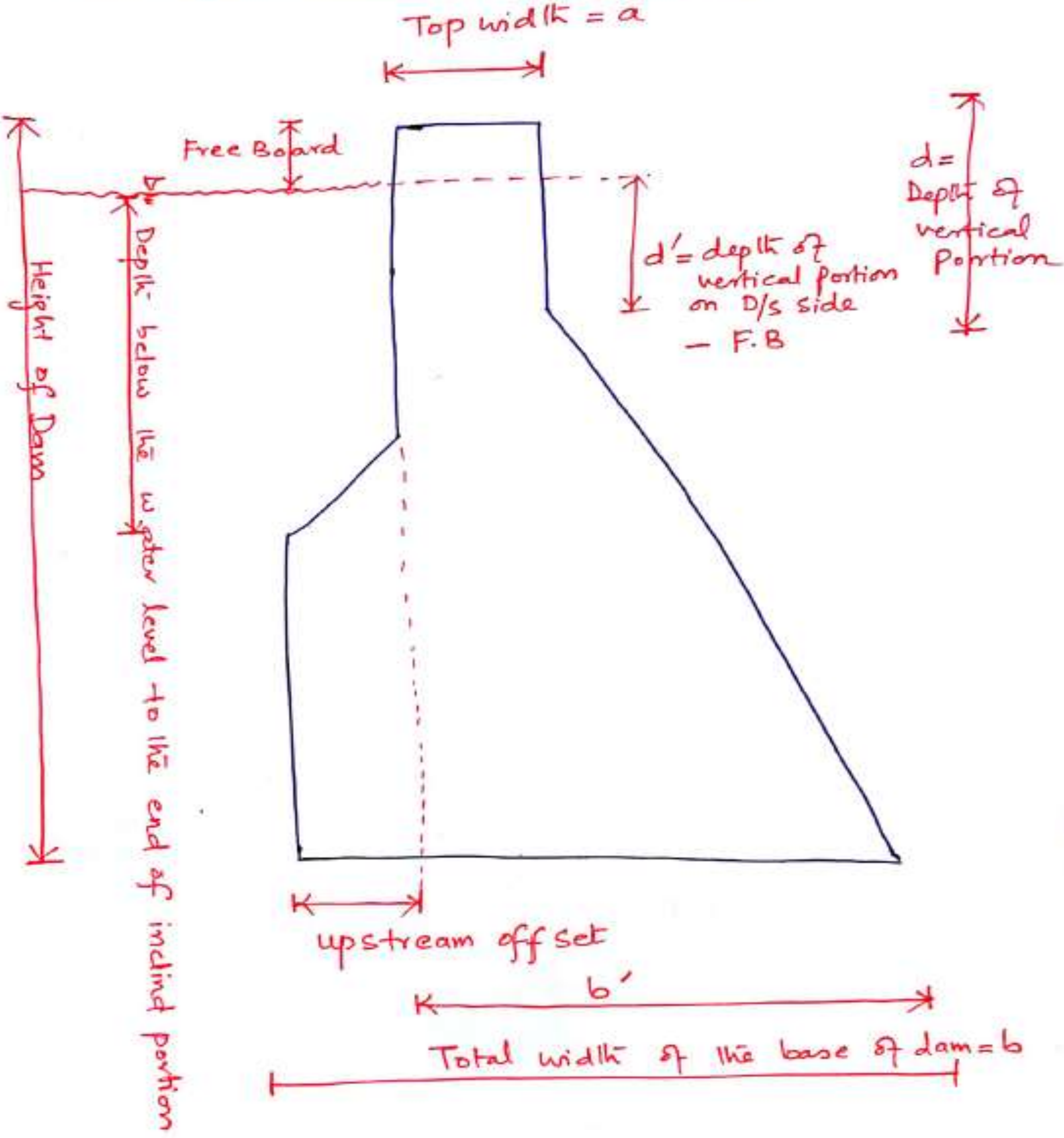
$$\boxed{F_i = 12006}$$

Design of Gravity Dam



Step of Procedure For Design of Gravity Dam

Step 1:- $H_{limiting} = \frac{\sigma_{all}}{\gamma_w (G - C_u + 1)}$ If > H_w low Gravity Dam

< H_w High Gravity Dam

Step 2:-

Top width "a"

* Free board = $1.5 h_{wave}$ = F.B
* Height of Dam = $H_D = H_w + F.B$

$a = 14\%$ of H_D

Step 3:- Base width = b' (without offset)

Condition 1 :- $b' = \frac{H_w}{\mu G}$ (No Sliding Criteria)

Condition 2 :- $b' = \frac{H_w}{\sqrt{G}}$ (No Tension Criteria)

larger than Condition 1 & 2 is Selected as b'

Step 4:- Depth of vertical portion on u/s side. h'

$h' = 2a\sqrt{G - C_u}$

Step 5:- upstream off set $= \frac{a}{16}$

Step 6:- Depth below the water level to the end of inclined portion in u/s side $= 3.14\, a\sqrt{G}$

Step 7:- Total base width $= b = b' + \frac{a}{16}$

Step 8:- Depth of vertical portion on D/S side

$d = d' + F.B$

d' is calculated from $\tan\theta = \frac{a}{d'}$

θ is calculated from $\tan\theta = \frac{b'}{H}$

Design of Gravity Dam:-

Example:- Design practical profile for a gravity Dam with the following data:-

Maximum Depth of water in the Reservoir = $H = 30m$

Specific Gravity of Dam Material = $G = 2.4$

Allowable compressive stress for the Dam Masonary

$$\sigma_{all} = 120 \frac{T}{m^2}$$

Height of wave = 1.2m

$\mu = 0.7$

No uplift pressure. $C_u = 0$.

Solution:-

① $$H_{limiting} = \frac{\sigma_{all}}{\gamma_w (G - C_u + 1)} = \frac{120 \times 1000}{1000\ (2.4 - 0 + 1)}$$

$$H_{limiting} = 35.294\ m > H_w = 30m$$

So it is Low Gravity Dam.

② Top width "a"

Free board = $1.5\ h_{wave} = 1.5 \times 1.2$

$$\boxed{F.B = 1.8m}$$

height of Dam = $H_D = H_W + F.B = 30 + 1.8$

$$\boxed{H_D = 31.8m}$$

$a = 14\%$ of HD

$a = 0.14 \times 31.8$

$$\boxed{a = 4.452 m}$$

(3) Base width "b'" (with out off set)

(i) – For No Sliding Criteria

$$b' = \frac{H_w}{\mu G} = \frac{30}{0.7 \times 2.4}$$

$b' = 17.85$

$$\boxed{b' \simeq 18 m}$$

(ii) – For No tension Criteria.

$$b' = \frac{H_w}{\sqrt{G}} = \frac{30}{\sqrt{2.4}}$$

$$\boxed{b' = 20 m}$$

use $\boxed{b' = 20 m}$

(4) Depth of vertical Portion on u/s side

$h' = 2a\sqrt{G - c_u}$

$h' = 2 \times 4.5\sqrt{2.4 - 0}$

$h' = 13.94 m$

$$\boxed{h' = 14 m}$$

(5) upstream off set $= \frac{a}{16}$

$= \frac{4.5}{16}$

$= 0.28\,m.$

(6) Depth below the water level to the end of inclined portion in u/s $= 3.14 a\sqrt{G}$

$= 3.14 \times 4.5 \sqrt{2.4}$

$= 21.6\,m.$

(7) total width of the base of the dam

$b = b' + \frac{a}{16} = 20 + 0.28$

$\boxed{b = 20.28\,m}$

(8) $\tan \theta = \frac{b'}{H} = \frac{20}{30}$

$\theta = \tan^{-1}\left(\frac{2}{3}\right)$

$\boxed{\theta = 44.42^{\circ}}$

(9) Depth of vertical portion on D/s (from WL on u/s side)

$\tan\theta = \frac{a}{d'} = \frac{4.5}{d'} \Rightarrow \tan\theta = \frac{4.5}{d'}$

$\frac{2}{3} d' = 4.5$

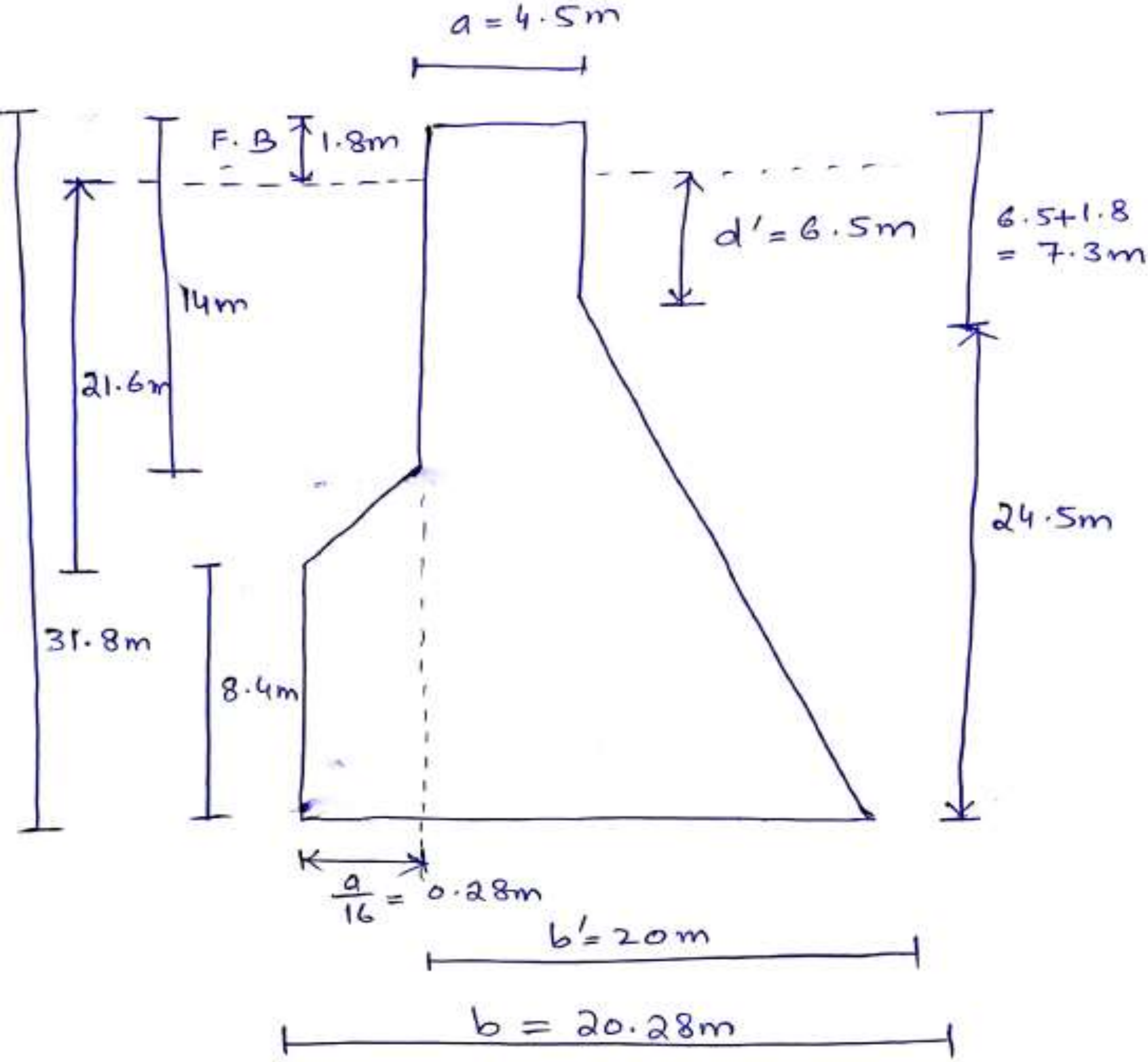
$d' = \frac{4.5 \times 3}{2}$

$\boxed{d' = 6.5\,m}$

depth of vertical Portion

$d = d' + FB = 6.5 + 1.8$

$\boxed{d = 7.3\,m}$


a = 4.5m
F.B
1.8m
d' = 6.5m
6.5+1.8
= 7.3m
14m
21.6m
24.5m
31.8m
8.4m
a/16 = 0.28m
b' = 20m
b = 20.28m

Thank You