Hydraulics Structures

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Dams

A dam is a hydraulic structure constructed across a river to store water in the reservoir formed on its U/S side

Classification of Dams

1. *<u>According to use</u>*

- Storage Dam
- Diversion Dam
- Detention Dam

Classification of Dams

2. *<u>According to construction Materials</u>*

A. Rigid Dam
- Gravity Dam
- Arch Dam

B. Non- Rigid Dam
- Earth Dam
- Rock fill Dam
- Combination of rock and earth fill Dam

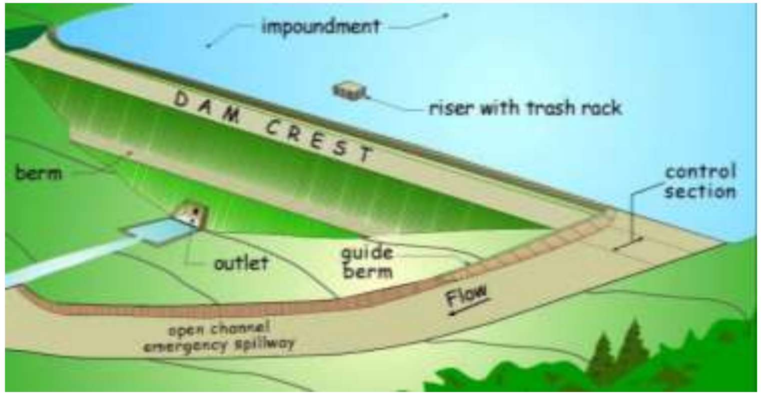
Factors Governing Selection types of Dams

Whenever it is decided to construct a dam, the first question that one face is which type of dam will be most suitable and most economical? Several factors are affecting selection of dam. These factors are discussed herein one by one.

1. Topography

Topography dictates the first choice of the type of dam.

- A narrow U-shaped valley, i.e. a narrow stream flowing between high rocky walls, would suggest a concrete overflow dam.
- A low plain country, would suggest an earth fill dam with separate spillways.
- A narrow V-shaped valley indicates the choice of an Arch dam



$$B < \frac{1}{4} h$$

Factors Governing Selection types of Dams

2. Geological and Foundation Conditions

Geological and Foundation conditions should be thoroughly surveyed because the foundations have to carry the weight of the dam.

- Solid rock foundations such as granite have strong bearing power and almost every kind of dam can be built on such foundations.

- Gravel foundations are suitable for earthen and rock fill dams.

- Silt and fine sand foundations suggest construction of earth dams or very low gravity dams.

- Clay foundations are likely to cause enormous settlement of the dam. Constructions of gravity dams or rock fill dams are not suitable on such foundations. Earthen dams after special treatments can be built.

Factors Governing Selection types of Dams

3. Availability of Materials

Availability of materials is another important factor in selecting the type of dam. In order to achieve economy in dam construction, the materials required must be available locally or at short distances from the construction site.

- If sand, gravel and stone is available a concrete gravity dam may be suitable.
- If coarse- and fine-grained soils are available, an earth dam may be suitable.

4. Length and height of the dam

- If the length of the dam is very long and its height is low; an earth dam would be a better choice.
- If the length is small and height is more ‘gravity dam’ is preferred

5. Road way

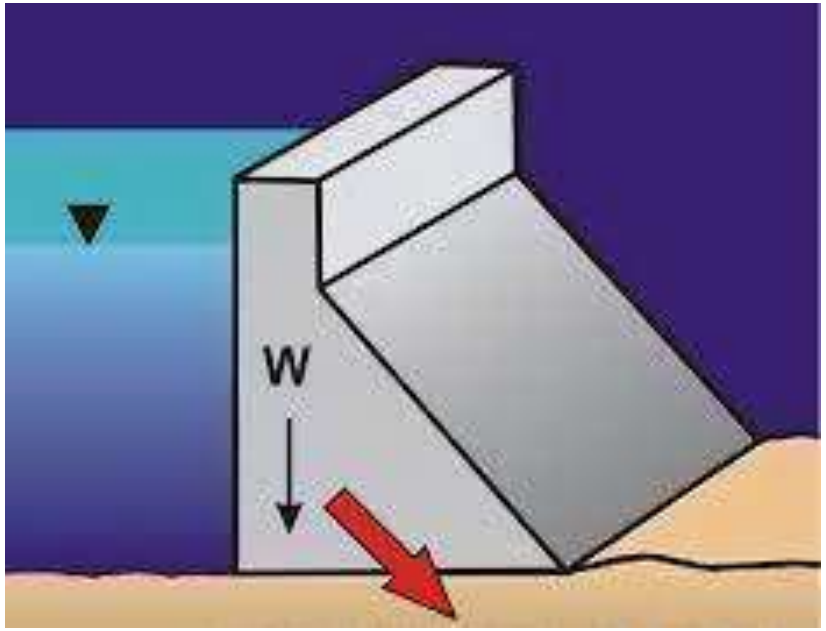
- If a road way is to be passed over the top of the dam, an earth dam would be preferred.

6. Life of the dam

- Concrete or masonry gravity dam have very long life; Earth and rock fill dams have intermediate life.

Economic Height of the Dam

The economic height of the dam is that height of the dam corresponding to which the cost of this dam per unit storage is minimum.

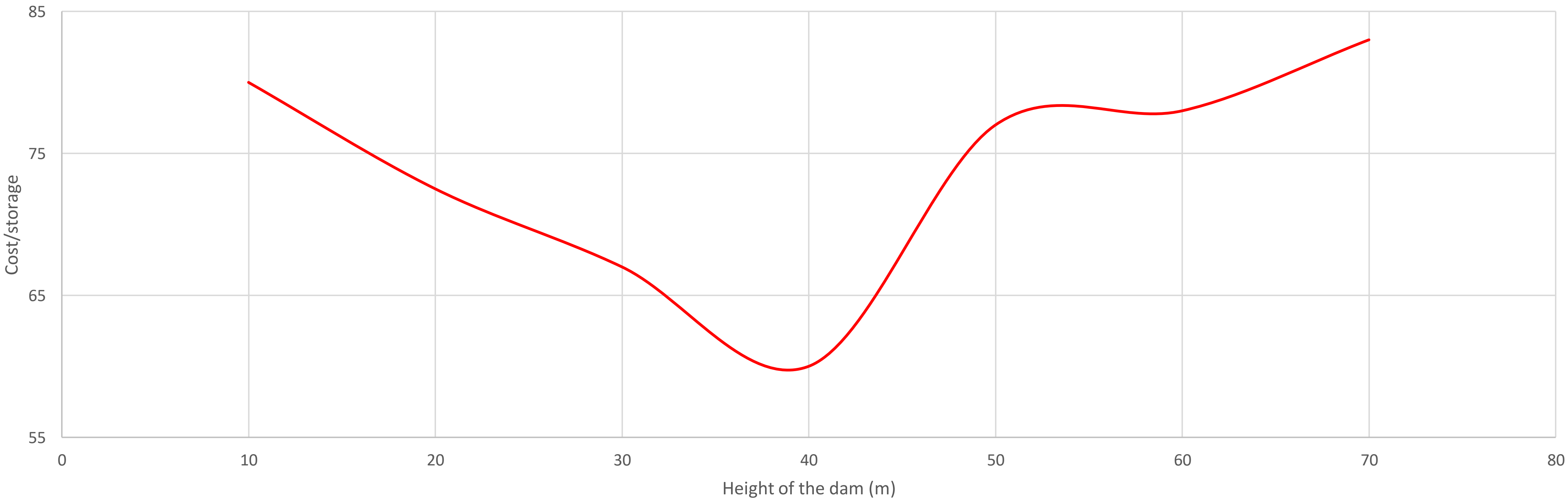


The construction cost increase with the dam height for each dam height, the reservoir is known from the capacity curve.

The construction cost per unit of storage for all possible dam height can be plotted. Then, the lowest point on the curve gives the economic dam height.

Example: The construction cost per certain possible height of the dam at a given site have been estimated and are tabulated below. The storage capacity for all these dam heights is also given. Find the economical dam height.

Dam Height (m)	Construction cost $*10^6$ ID	Storage $*10^6$ m^3
10	4,000	50
20	8,000	110
30	12,000	180
40	18,000	300
50	27,000	350
60	39,000	500
70	50,000	600

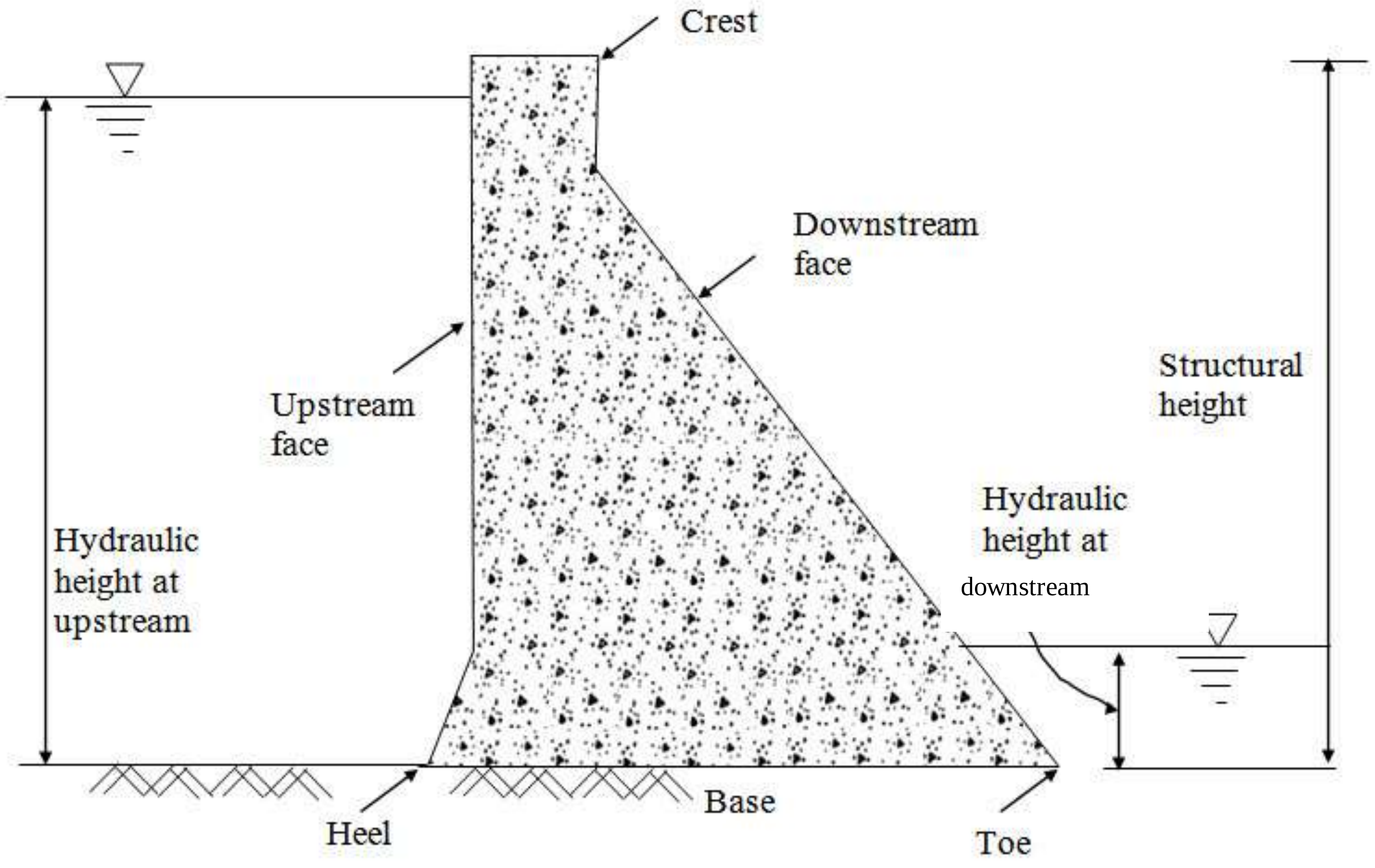


Concrete Gravity Dam

The structure is designed in such a way that its weight resists the forces exerted upon it. It may be constructed of concrete or masonry.

Forces Acting on Gravity Dam

- Water Pressure
- Uplift Pressure
- Silt Pressure
- Wave Pressure
- Pressure due to Earthquake
- Ice Pressure
- Weight of the Dam



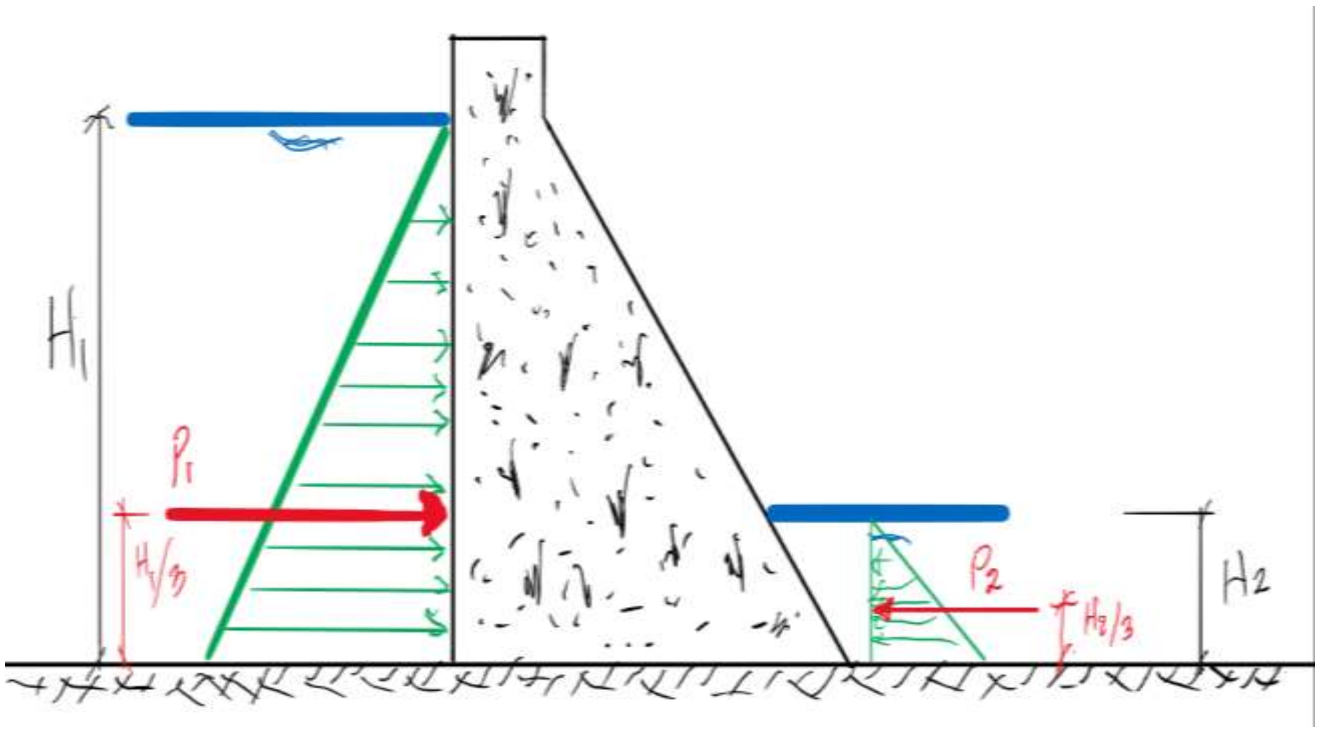
❖ Water Pressure

Water pressure on the upstream side is the main destabilizing force in gravity dam. Downstream side may also have water pressure and its magnitude is much smaller as compared to the upstream water pressure.

- When the upstream face of the dam is vertical, as shown below, then the water pressure would be calculated as follow: -

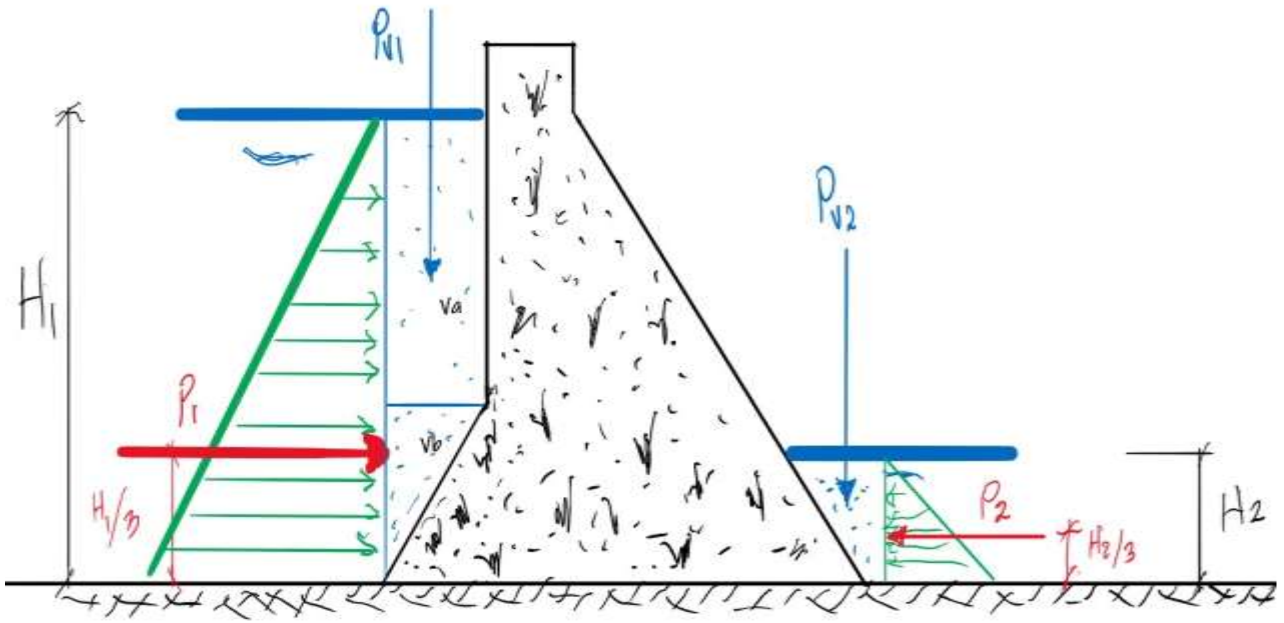
$$P_1 = \frac{1}{2}\,\gamma\, H_1^2$$

$$P_2 = \frac{1}{2}\,\gamma\, H_2^2$$



❖ Water Pressure

➢ When the upstream face of the dam is Partially vertical, as shown below, then the water pressure acting the dam would be calculated as follow: -



1. Horizontal components (P_1 and P_2)

$$P_1 = \frac{1}{2}\gamma H_1^2 \qquad P_2 = \frac{1}{2}\gamma H_2^2$$

2. Vertical components (P_{V1} and P_{V2})

$$P_{V1} = \gamma V_1 \qquad P_{V2} = \gamma V_2$$

V_1 & V_2 *are the volume of water*

$$V_1 = V_a + V_b$$

- 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 joint between the body of the dam.
- It is the second major external force and must be accounted for in all calculations. Such an uplift force virtually reduces the downward weight of the body of the dam and hence, acts against the dam stability.

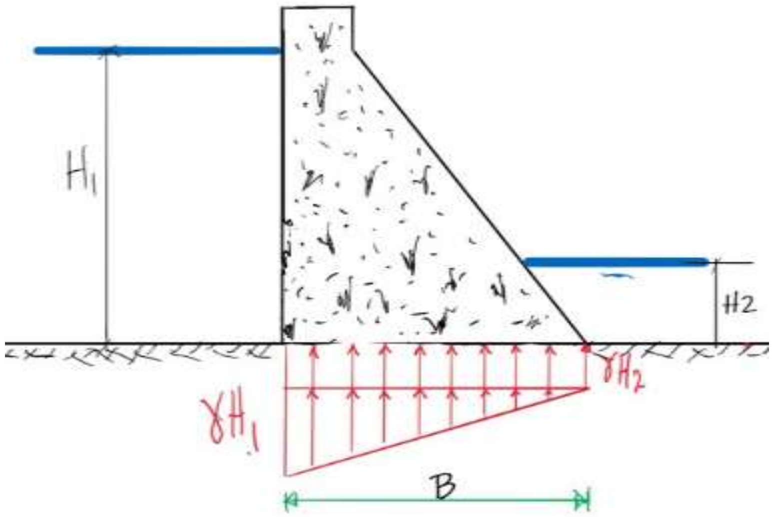
❖ Uplift Pressure

➢ *Without Gallery*

$$U_1 = \gamma H_2 \,.\, B$$

$$U_2 = \frac{1}{2}\,(\gamma H_1 - \gamma H_2).\,B$$

B is the bottom width of the dam.



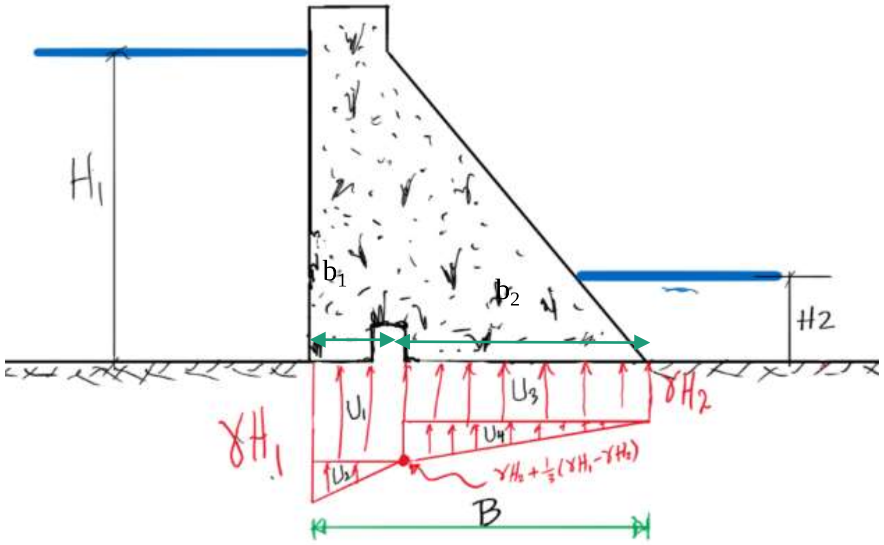
➢ *With Gallery*

$$U_1 = \left[\gamma H_2 + \frac{1}{3}(\gamma H_1 - \gamma H_2)\right].\,b_1$$

$$U_2 = \left[\gamma H_1 - \gamma H_2 - \frac{1}{3}(\gamma H_1 - \gamma H_2)\right].\,\frac{b_1}{2}$$

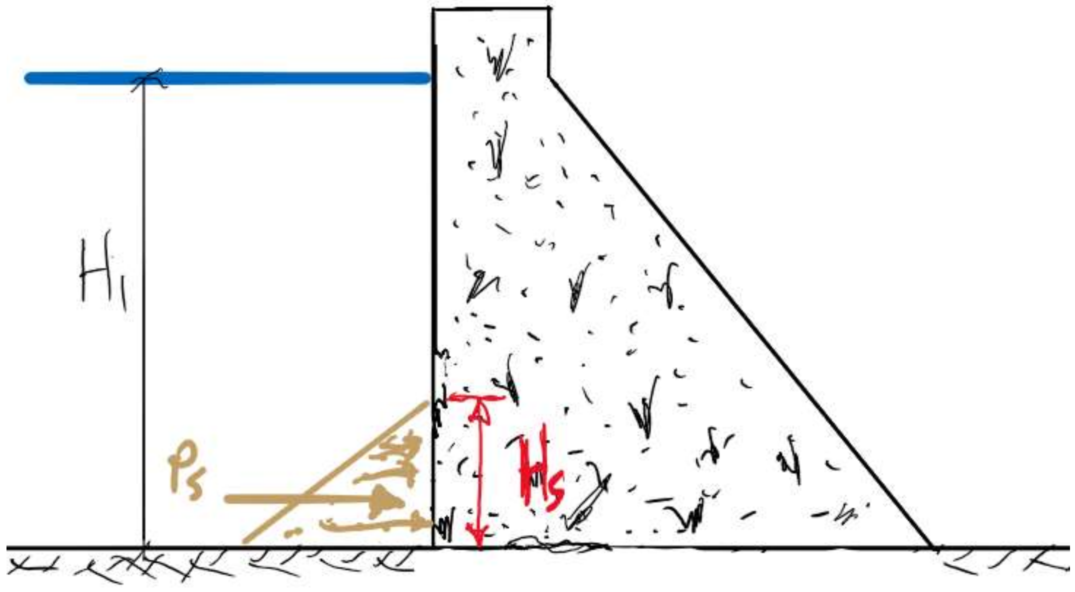
$$U_3 = \gamma H_2 \,.\, b_2$$

$$U_4 = \frac{1}{3}(\gamma H_1 - \gamma H_2)\,.\,\frac{b_2}{2}$$



- **Silt Pressure**

$$P_s = \frac{1}{2}\gamma_s {H_s}^2 K_a$$



H_s: height of silt

γ_s: Submerged unit weight of silt material

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

$\emptyset$: is the angle of internal friction of Soil, and cohesion is neglected.

Note: -If the upstream face of the dam is inclined, the vertical weight of silt on the slope acts as vertical force.

❖ **Wave Pressure** Wave pressure depends on the height of the wave developed.

$$h_w = 0.032\sqrt{V * F} + 0.763 - 0.27\sqrt[4]{F} \qquad For\ F \le 32\ km$$

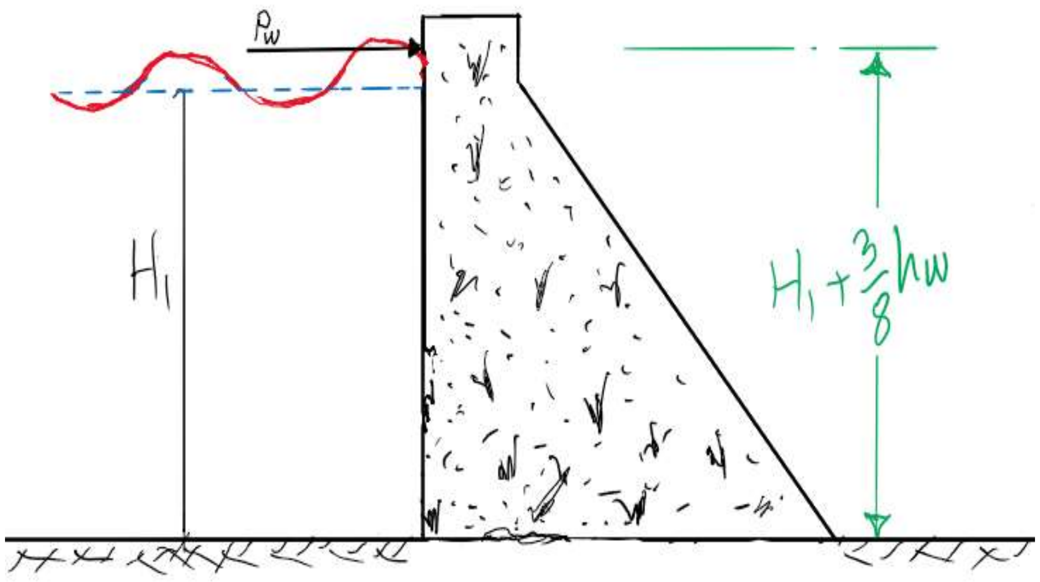
$$h_w = 0.032\sqrt{V * F} \qquad For\ F > 32\ km$$

where:

h_w: height of the wave (m)

V: Wind velocity (km/hr)

F: Straight length of water expanse (km)



$P_w = 2000\,\gamma_w\,h_w^2$ in kg/m

$P_w = 2\,\gamma_w\,h_w^2$ in ton/m

P_w: wave pressure

This force acts at a distance ($\frac{3}{8}\boldsymbol{h_w}$) above the reservoir water surface

❖ Earthquake Force

a. *Effect of Vertical Acceleration*

- When the acceleration is vertically upward, the inertia force ($F_v = W * K_v$) acts vertically downward, these increasing the downward weight.

- When the acceleration is vertically downward, the inertia force acts upward and decreasing the downward weight.

Therefore:

Net weight of the dam = $W(1 \pm K_v)$

where:

W: weight of the dam

K_v : Earthquake coefficient of vertical acceleration

(+): for acceleration upward

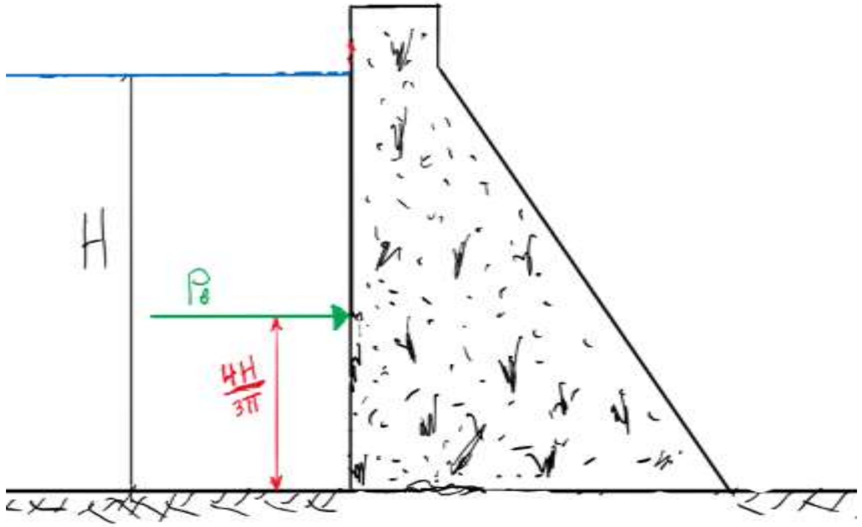
(-): for acceleration downward

➢ Earthquake Force

b. Effect of Horizontal acceleration

❑ *Hydrodynamic pressure*

The horizontal acceleration of the dam and foundation toward the reservoir, causes a momentary increasing in the water pressure. The increase in water pressure 'P_e' is given by:



$$P_e = 0.55\, K_h * \gamma_w H^2$$

where:

K_h : earthquake coefficient in horizontal acceleration

H: upstream water depth

This force acts at a distance $\frac{4H}{3\pi}$ above the bed level of the dam

❑ *Horizontal inertia force*

The inertia force acts in a direction opposite to the acceleration imparted by the quake force:

$$F_H = W * K_h$$

This force can be considered at the center of gravity of the dam.

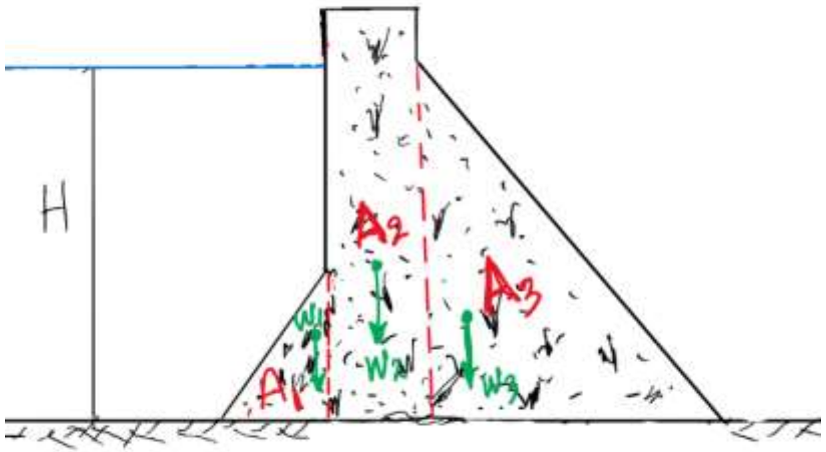
❖ Weight of the Dam

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 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

$$W_1 = A_1 * 1 * \gamma_{Conc}$$

$$W_2 = A_2 * 1 * \gamma_{Conc}$$

$$W_3 = A_3 * 1 * \gamma_{Conc}$$



❖ Ice force

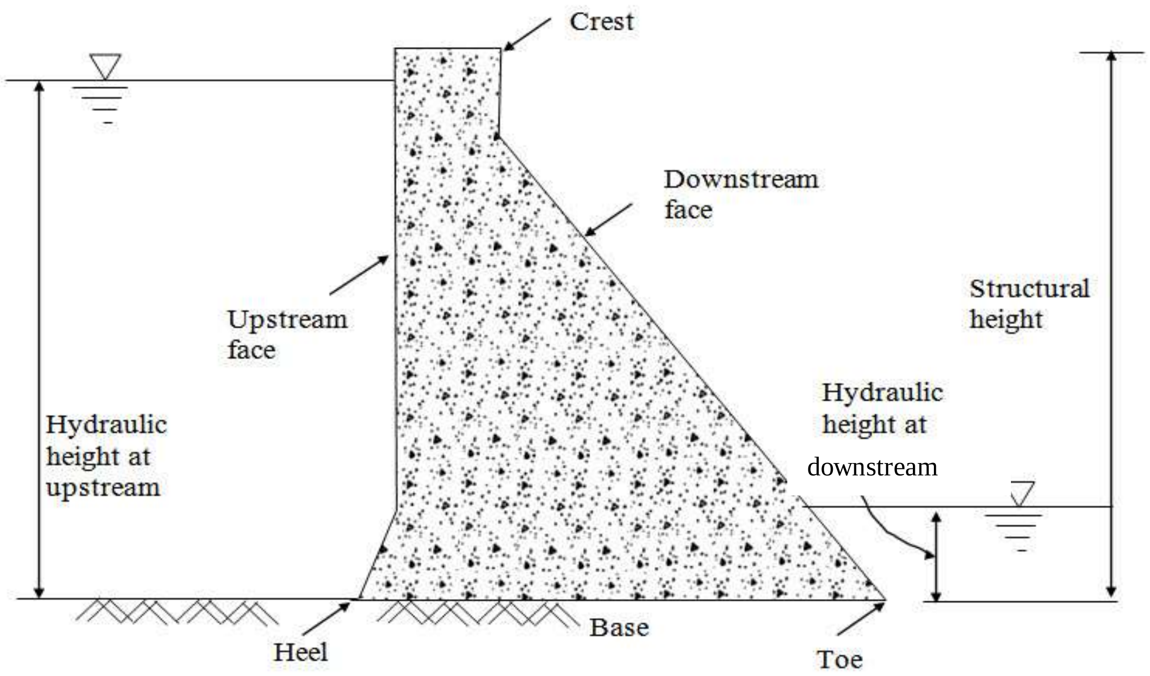
The coefficient of thermal expansion of ice being five times more than of concrete. The ice force acts linearly along the length of the dam at the reservoir level. The average value of (5 kg/cm^2) or (50 ton/m^2) may be taken as an ice force.

- **By Overturning**

If the resultant of all forces acting on a dam at any section of its section passed outside the toe, the dam shall rotate and overturning about the toe. Therefore, the factor of safety against overturning is:

$$F.S_{over} = \frac{\sum Righting\ Moments}{\sum Overturning\ Moments}$$

$$F.S_{over} = \frac{\sum M_R}{\sum M_O} > 2$$



- **Sliding or shear failure**

Sliding will occur when the net horizontal force at the base of the dam exceeds the frictional resistance developed at that level.

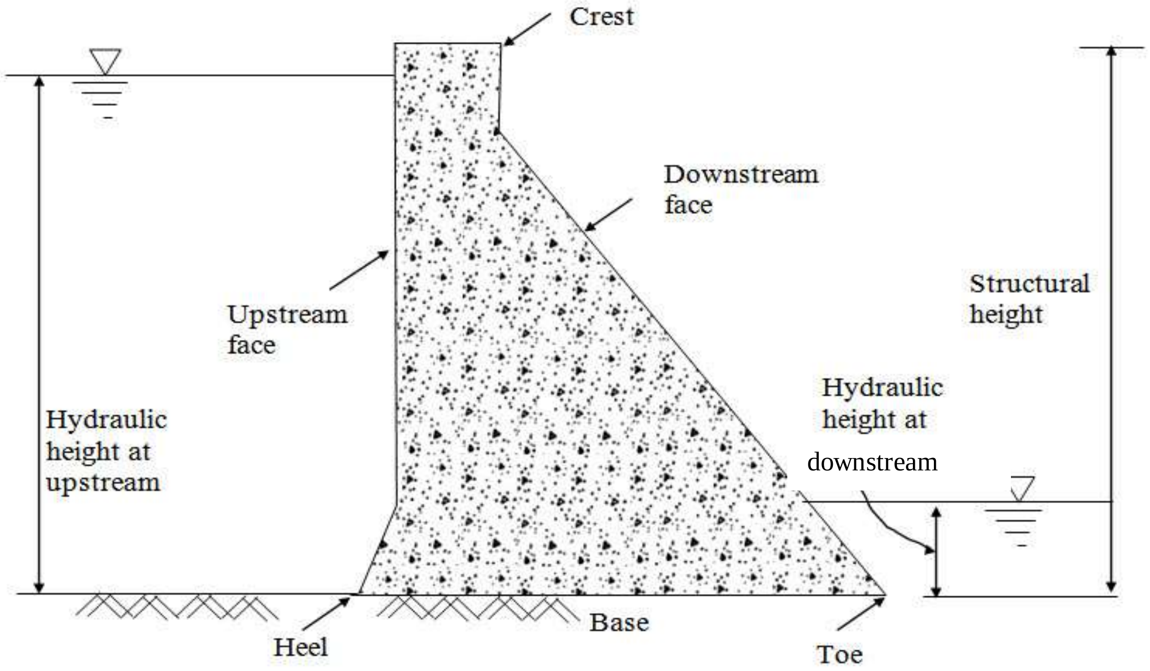
$$F.S_{Sliding} = \frac{\mu \sum V}{\sum H} = \frac{\mu \sum (W-u)}{\sum H} > 1$$

where:

$\sum(\boldsymbol{W}-\boldsymbol{u})$: net vertical forces

$\sum \boldsymbol{H}$: Sum of horizontal forces causes the sliding.

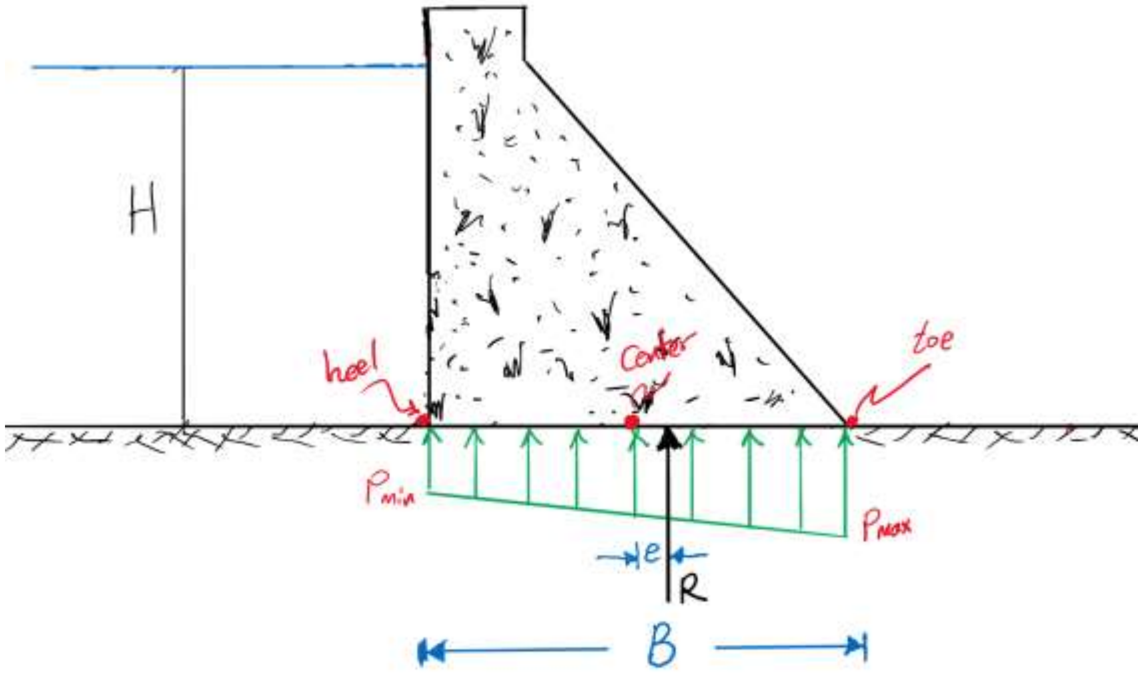
$\boldsymbol{\mu}$: Coefficient of friction (0.65-0.75)



- **Compression or crushing**

A dam may fail by the failure of its materials. The compression stress produced may exceed the allowable stress and dam materials may get crushed. The vertical stress distribution at the base is given by:

$$P_{\substack{Max \\ Min}} = \frac{\sum V}{B} \mp \frac{M_C}{I} = \frac{\sum V}{B}\left(1 \mp \frac{6e}{B}\right)$$



where:

$\frac{\sum V}{B}$: direct stress

$\mp\frac{M_C}{I}$: bending stress = $\frac{6*V*e}{B^2}$

(+) : will be used for calculating normal stress of the toe.

(-) : will be used for calculating normal stress of the heel.

$\sum V$: Total vertical forces

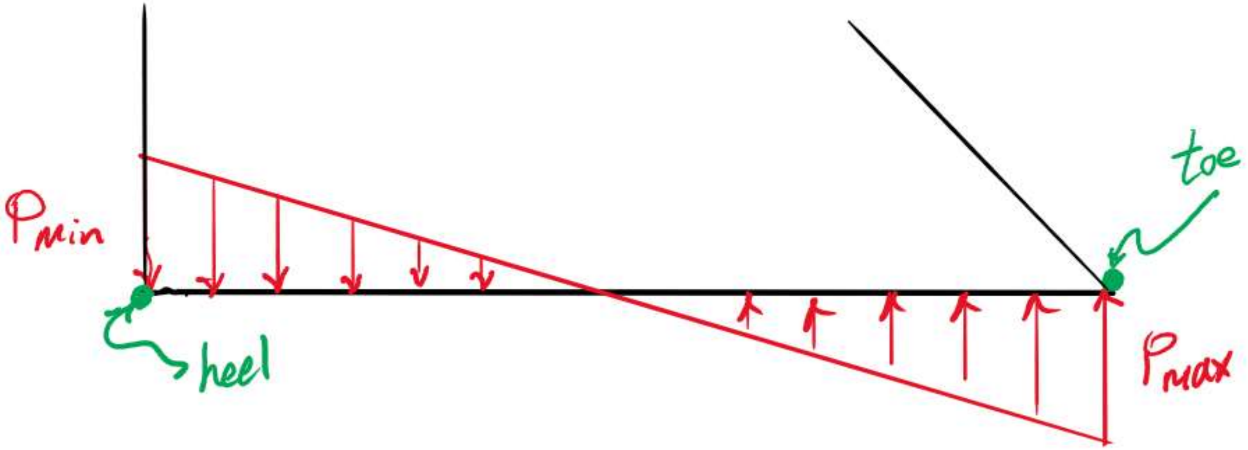
B: Base width of the dam

e: eccentricity of the resultant from the center of the base.

- **Tension** For the present equation:

$$P_{min} = \frac{\sum V}{B}\left(1 - \frac{6e}{B}\right)$$

If $\boldsymbol{e} > \frac{\boldsymbol{B}}{\boldsymbol{6}}$ the normal stress at the *heel* will be (-ve) or tension as shown in the figure:



No tension should be permitted at any point of the dam. The eccentricity **e** should be less than $\frac{\boldsymbol{B}}{\boldsymbol{6}}$. ($\boldsymbol{e} < \frac{\boldsymbol{B}}{\boldsymbol{6}}$). Thus, the result should always lie within the middle third of the base.

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