Hydraulics Structures

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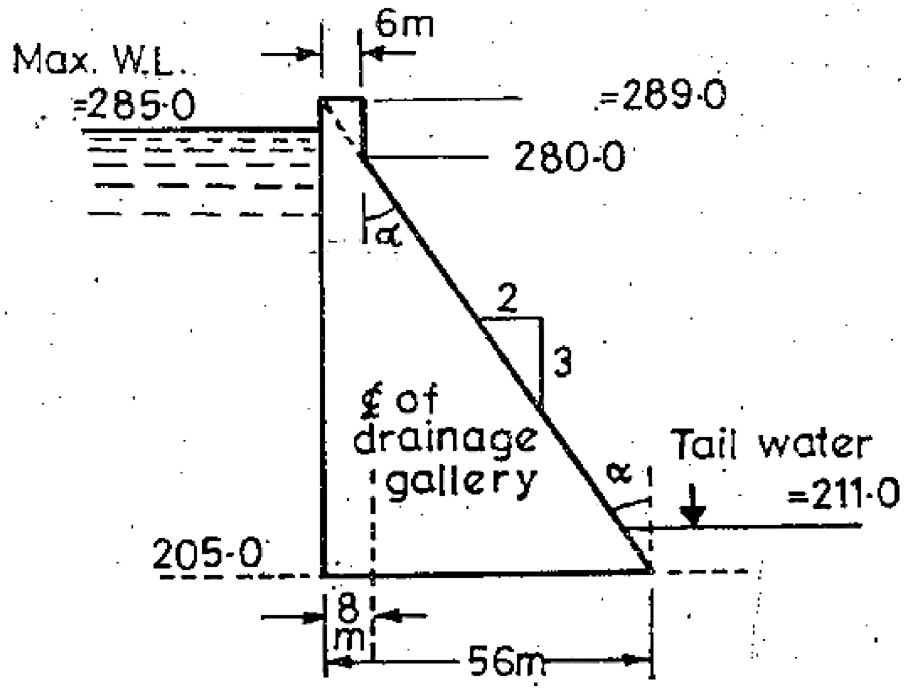
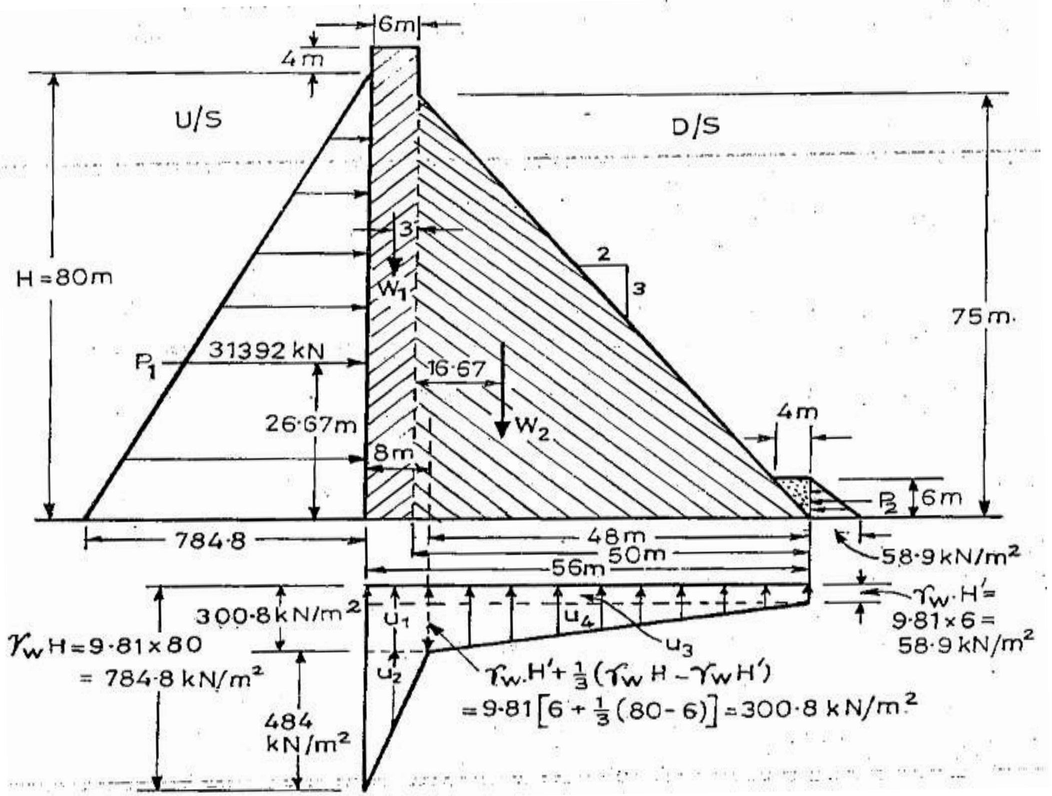
Example The figure shows the section of a gravity dam (non-overflow portion) built of concrete. *Calculate (neglecting earthquake effects) the maximum vertical stresses at the heel and toe of the dam.* Assume weight of concrete = 23.5 kN/m, and unit length of dam. Allowable stress in concrete may be taken 2500 kN/m and assuming γ_w = 9.81 kN/m.

Solution:

Consider 1 m length of the dam. The Table below listed all the forces acting the dam and the moment value for each force as well.



Name of the force	Designation if given	Magnitude in kN	Lever arm in m	Moments about toe in kN.m
Vertical forces				
Downward weight of the dam	W_1	(+) $84 \times 6 \times 1 \times 23.5 = 11{,}844$	53.0	(+) 6,27,732
	W_2	(+) $\frac{1}{2} \times 50 \times 75 \times 1 \times 23.5 = 44{,}063$	33.33	(+) 14,68,620
Weight of water supported on d/s face	—	(+) $\frac{1}{2} \times 4 \times 6 \times 1 \times 9.81 = 118$	1.33	(+) 157
		$\Sigma V_1 = 56{,}025$		$\Sigma M_1 = (+)\ 20{,}96{,}509$
Uplift pressures	U_1	(–) $300.8 \times 8 \times 1 = 2406$	52.0	(–) 1,25,112
	U_2	(–) $\frac{1}{2} \times 484 \times 8 \times 1 = 1936$	53.33	(–) 1,03,247
	U_3	(–) $58.9 \times 48 \times 1 = 2827$	24.0	(–) 67,848
	U_4	(–) $\frac{1}{2} \times 241.9 \times 48 \times 1 = 5806$	32.0	(–) 1,85,792
		$\Sigma V_2 = (-)\ 12{,}975$		$\Sigma M_2 = (-)\ 4{,}81{,}999$
		$\Sigma V = 56{,}025 - 12{,}975 = 43050$		
Horizonal *Water pressure*				
On u/s face	P	$\frac{1}{2} \times 784.8 \times 80 \times 1 = 31{,}392$	26.67	(–) 8,37,225
On d/s face	P'	(–) $\frac{1}{2} \times 58.9 \times 6 = (-)\ 177$	2.0	(+) 354
		ΣH (towards downstream) = 31,215		$\Sigma = (-)\ 8{,}36{,}871$



$$\Sigma M = \text{Net (+) moment} = 20{,}96{,}509 - 4{,}81{,}999 - 8{,}36{,}871 = 7{,}77{,}639 \text{ kN-m}$$

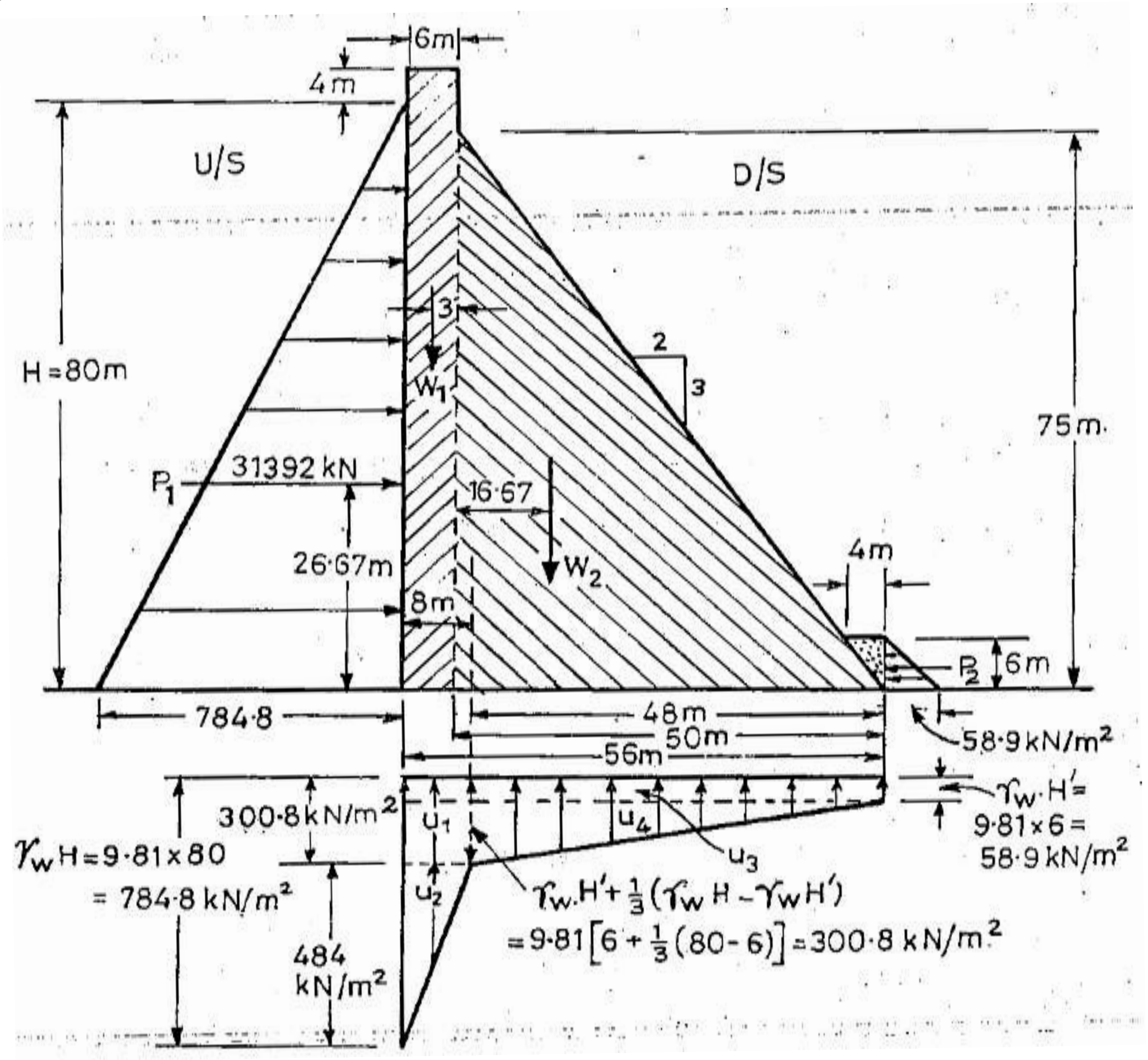
The various forces acting the dam are drawn in the figure below.

Distance of resultant from the toe $(\bar{x}) = \dfrac{\sum M}{\sum Vertical\ Forces\ (V)}$

$$= \frac{777693}{43050}$$

$$(\bar{x}) = 18.06 \text{ m}$$

$$\text{Eccentricity (e)} = \frac{56}{2} - 18.06 = 9.94\ m$$



Vertical stress P_v is given as : $P_{\substack{Max\\Min}} = \dfrac{\sum V}{B} \mp \dfrac{M_C}{I}$

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

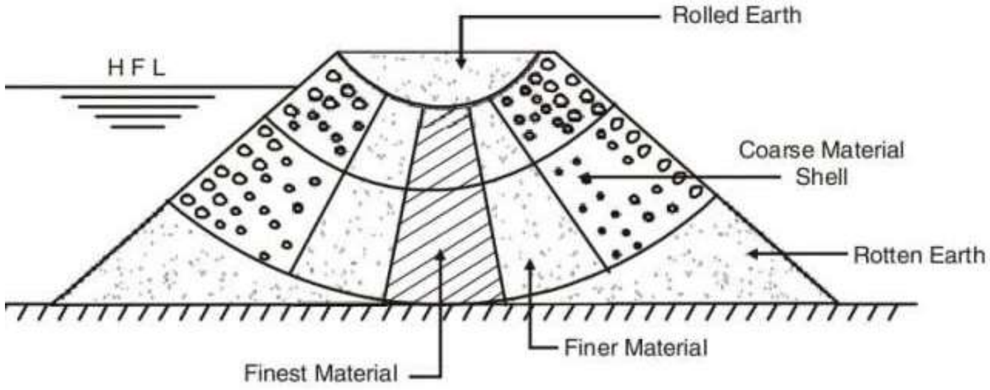
$$P_{\substack{Max\\Min}} = \frac{43050}{56}\left(1 \mp \frac{6 * 9.94}{56}\right) = 768.8\ (1 \mp 1.06)$$

$$P_{Max\ (toe)} = 768.8 * \ (2.06) = 1587.6\ kN/m^2$$

$$P_{Min\ (heel)} = 768.8 * \ (-\ 0.06) = -49.97\ kN/m^2$$

Earth Dam Depending upon the method of construction earth dams can be divided into two categories:

- Rolled fill dams.
- Hydraulic fill Dam.



Rolled fill dams.

This type can be farther be subdivided into the following types:

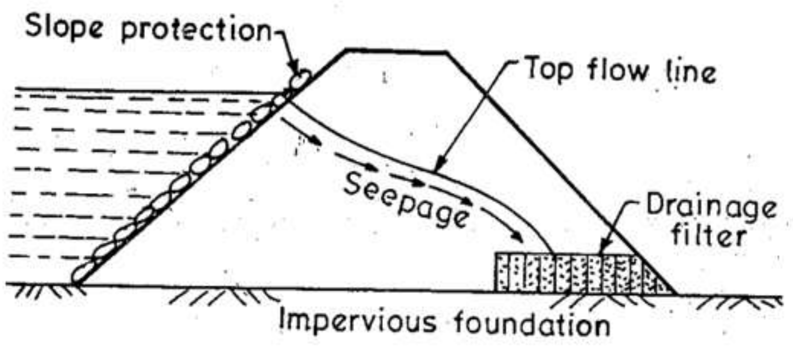
- Homogeneous embankment dam.
- Zoned embankment dam.
- Diaphragm dam.

Hydraulic fill dams.

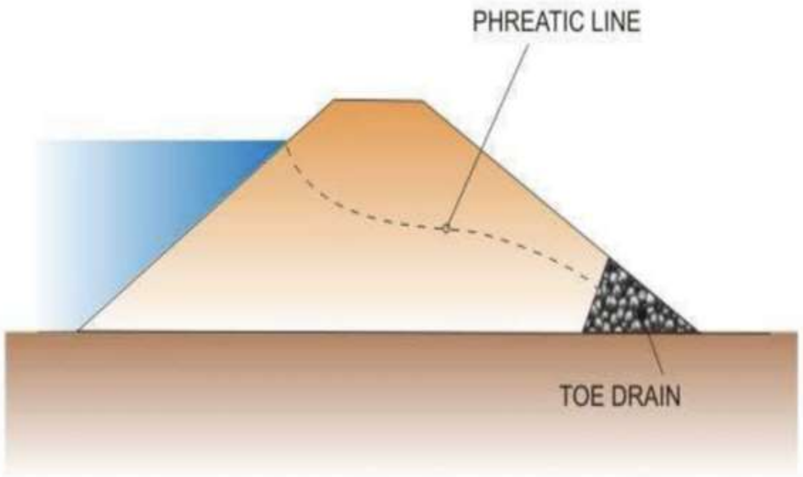
In this methods of construction, the dam body is constructed by excavating and transporting soil by using water.

- **Homogeneous embankment dam**

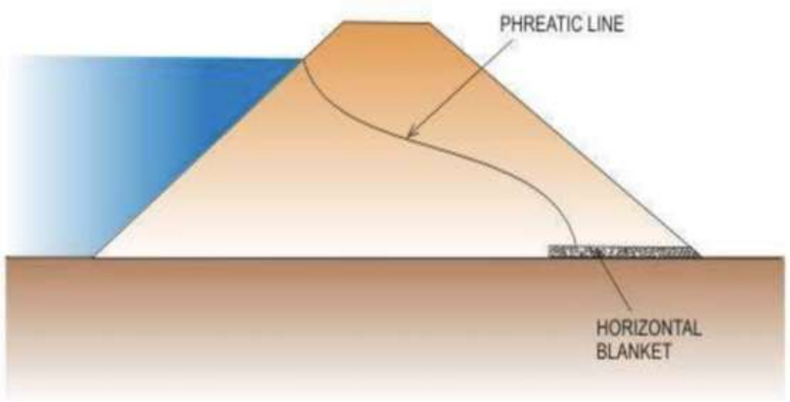
It is the simplest type of embankment, consists of single material and is homogeneous. A purely homogeneous section has been replaced by a modified homogeneous section in which internal drainage system in the form of horizontal filter drain or rock toe is provided. The horizontal drainage filter or rock toe to keep the phreatic line (top seepage line) with in the body of the dam.



Simple Homogeneous Earth dam



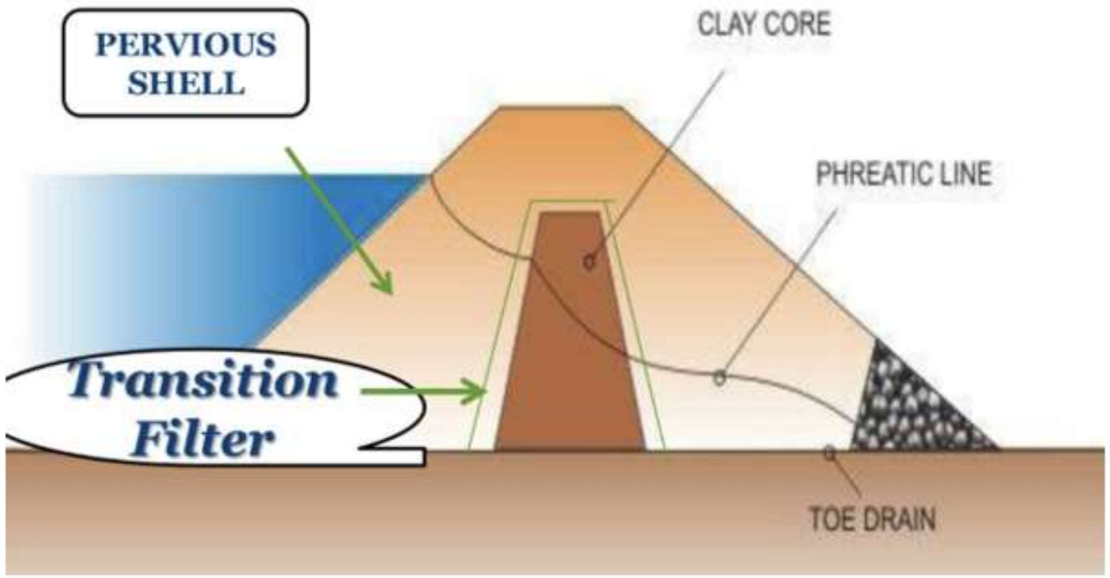
Homogeneous Earth dam with Rock Toe.



Homogeneous Earth dam with Horizontal Filter

- **Zoned embankment dam**

Zoned embankments are usually provided with central impervious core covered by transition zone which finally surrounded by more pervious zone (outer pervious zone). A suitable drainage system in the form of horizontal drain or rock toe is also provided. Central zone, to check the seepage through the dam. Transition zone, to prevent piping through cracks which may develop in the core. Outer zone, to give stability and to control the core and distribute the load on large area of foundation.

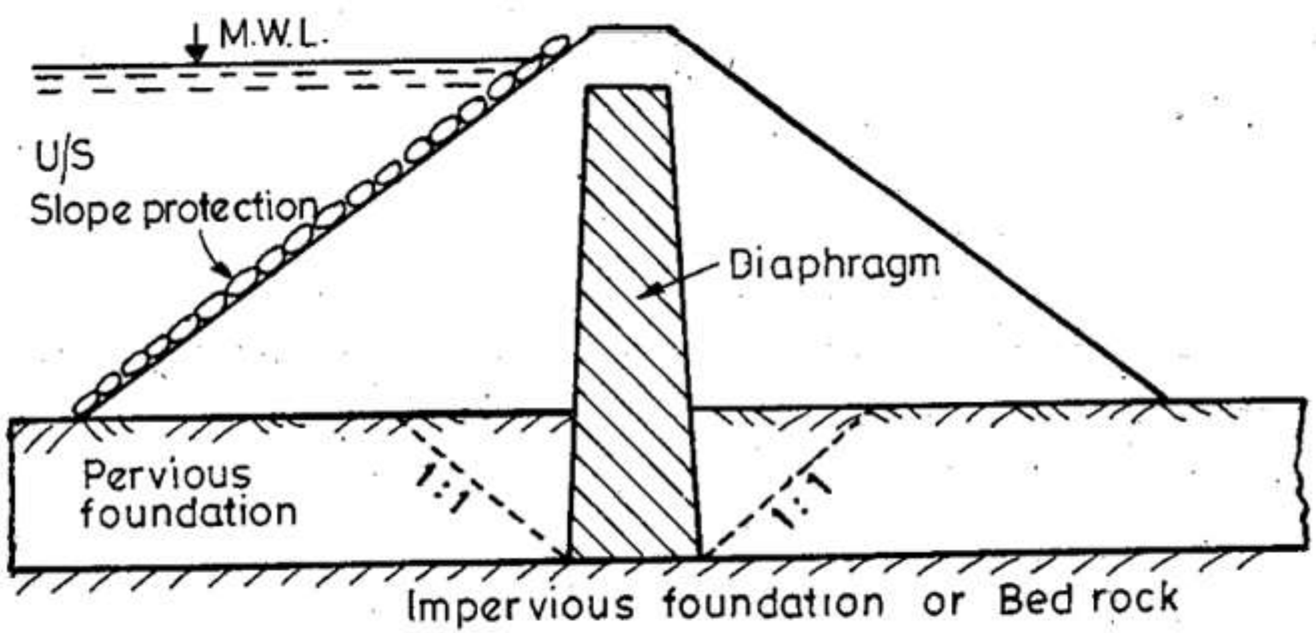


Zoned Embankment Dam

- **Diaphragm Earth dam**

Embankments have a thin impervious core (in order to check the seepage) which is surrounded by earth or rock fill. The impervious core called diaphragm and it is made from steel, concrete ...etc.

The diaphragm acts as water barrier to prevent seepage through the dam. It may be placed either at the center of the section as a central vertical core, or at the upstream face as a blanket.



Diaphragm Embankment Dam

Causes of Failure of Earth Dam

The types of failures in earth dams are:

- ❑ Hydraulics failure (40%)
- ❑ Seepage failure (30%)
- ❑ Structural failure (30%)

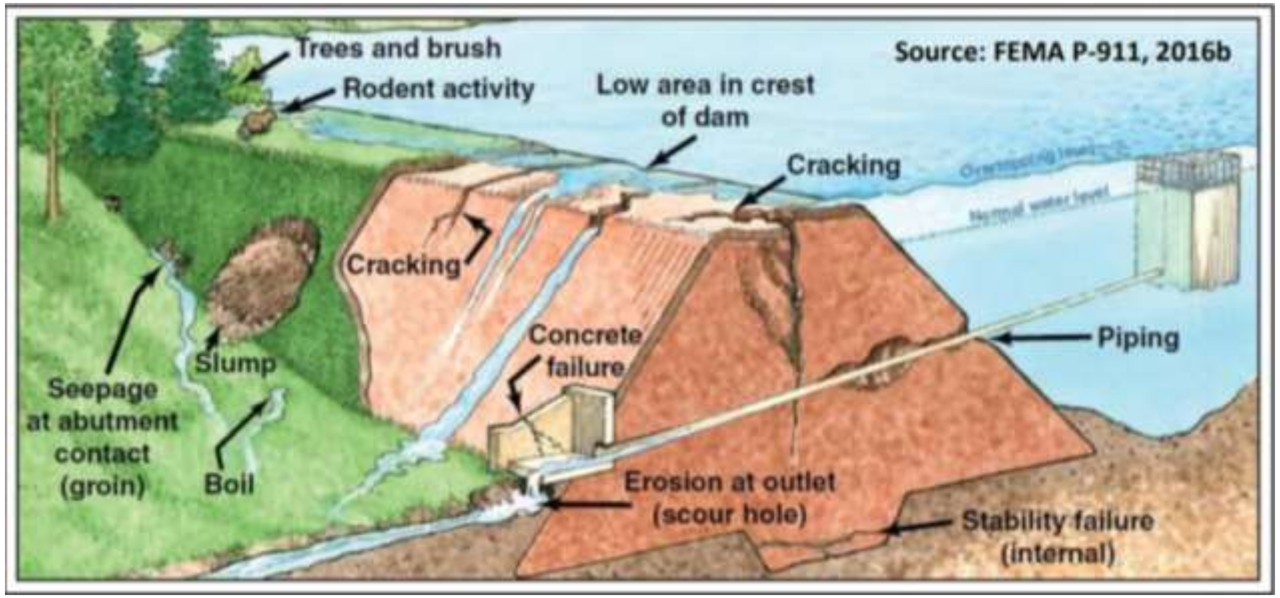
- *Hydraulics failure*

- **Over Topping** … The water may overtop the dam if the design flood is underestimated, or the spillway of insufficient capacity or spillway gates are not property operated.

- **Erosion of upstream face (wave erosion)** … The effect of wave is to wash out earth from the upstream slope in absence of proper slope protection in the form of riprap. The wave developed near the water surface may cause slip of the U/S face.

- **Toe Erosion** … It is due to either the tail water or cross current that may come from spillway buckets or from area of outlets.

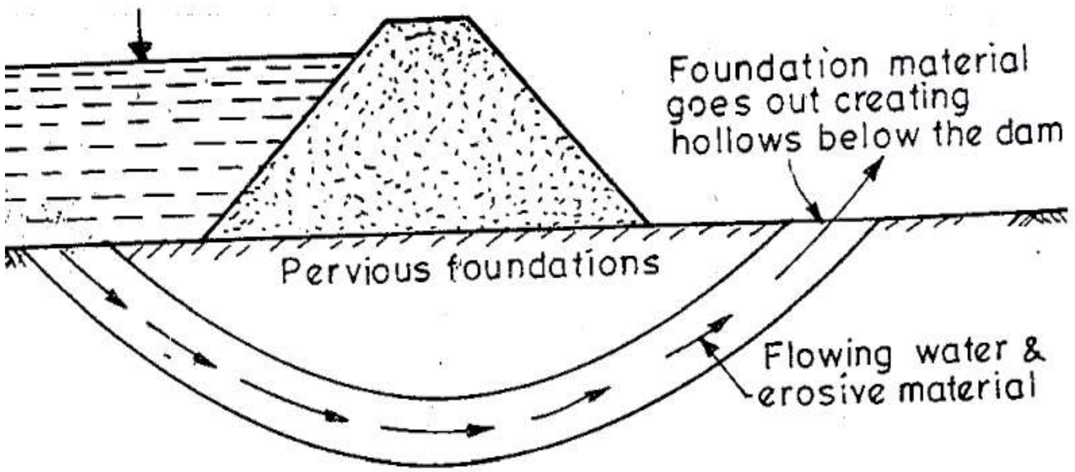
- **Erosion of downstream face by gully formation** … Proper maintenance required (grassing), and good drainage system should be provided to the downstream sides.



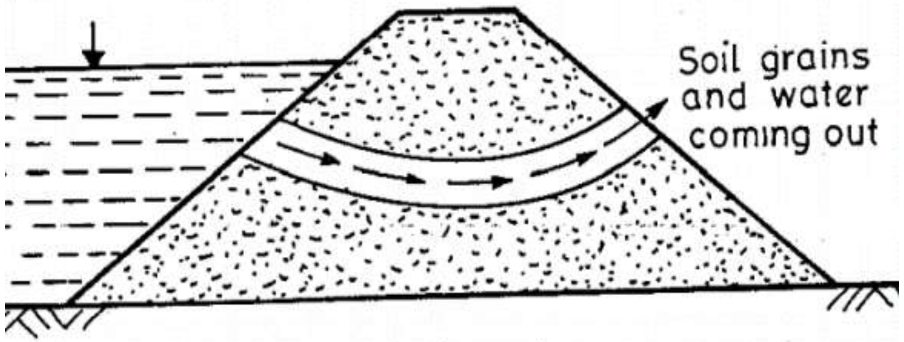
- **Cracking due frost action** … Frost in the upper portion of the dam may cause heaving and cracking of the soil with dangerous seepage and consequent failure especially for dams in areas of low temperatures.

➢ *Seepage failure*

- **Piping through the foundation**
- **Foundation materials goes out creating failure of this foundation.**
- **Piping through the Dam Body**



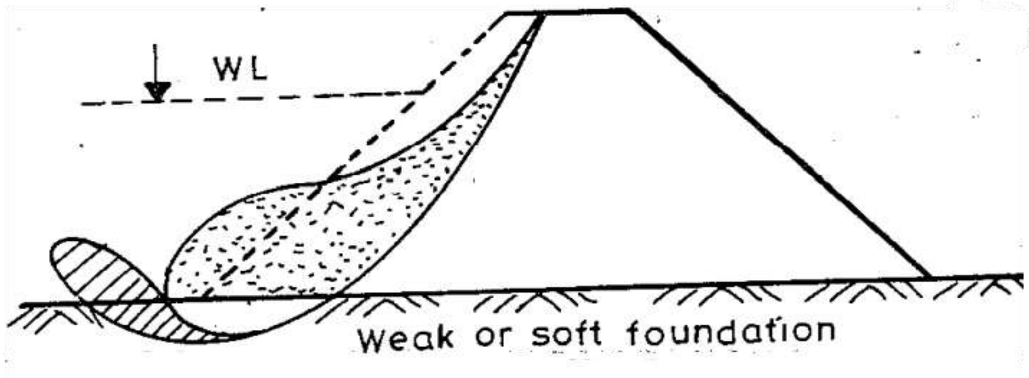
Piping through the dam foundation.



Piping through the dam body.

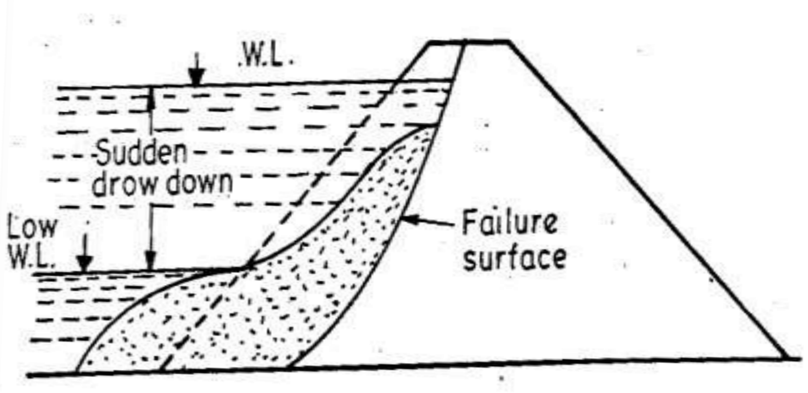
➢ *<u>Structural failure</u>* Structural failure is generally caused by share failure causing slides:

❖ **Foundation slides** … When the foundation of earth dam of soft soil (fine sand or soft clay); the dam may slide over the foundation, the top of embankment gets cracked.

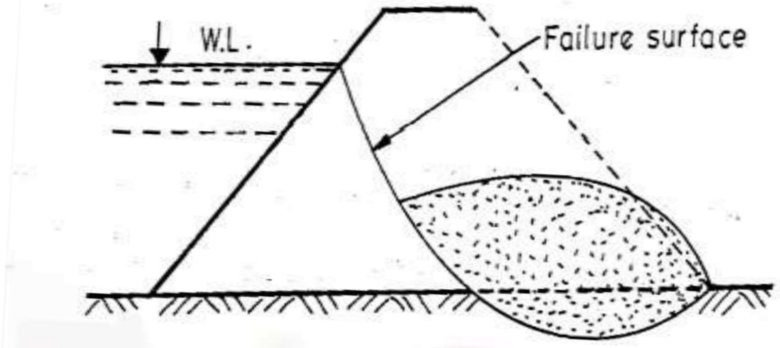


Sliding due to soft or weak foundation.

❖ **Slide in embankment** … When the embankment slopes are too steep, they may slide causing dam failure.



U/S slope slide due to sudden draw-down.

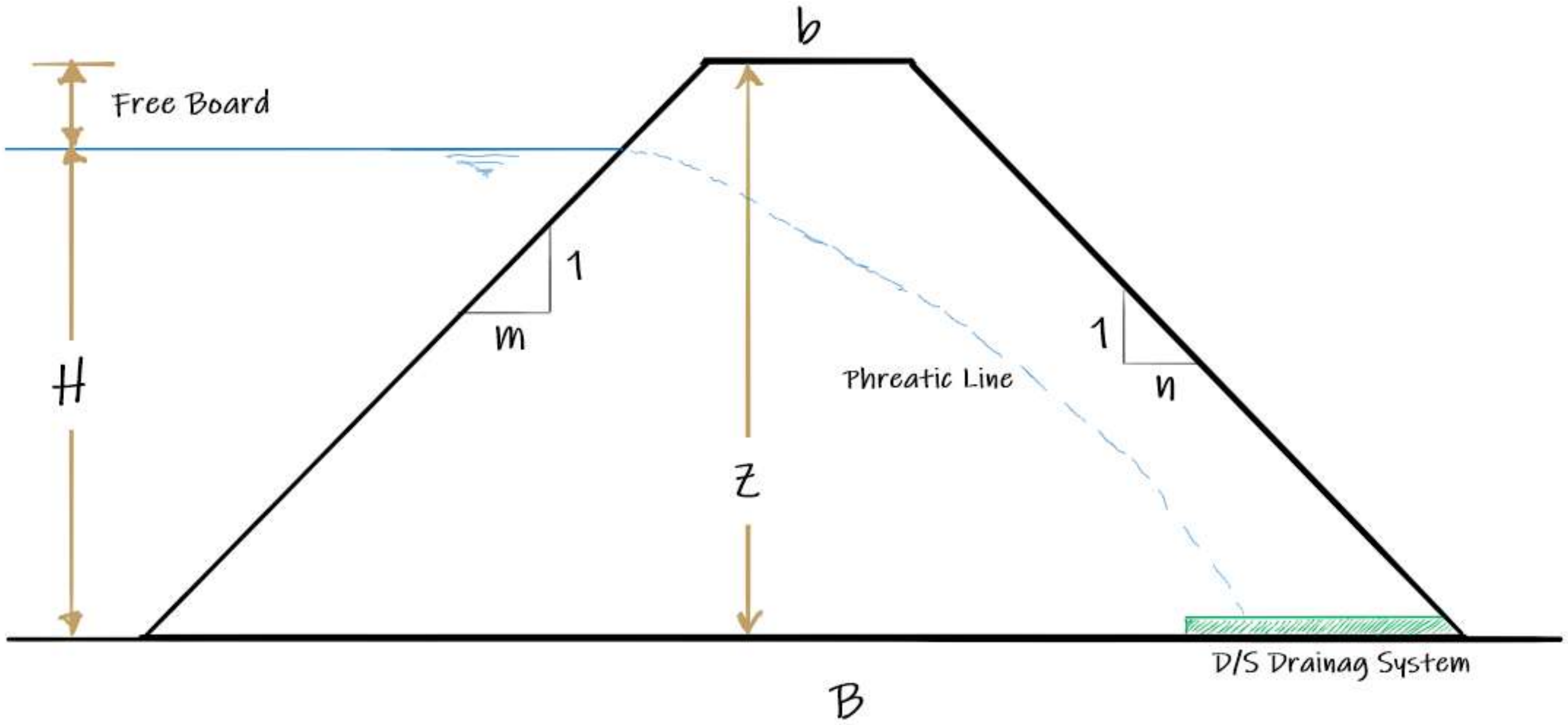


D/S. slope slide during full reservoir condition.

Selection of suitable section of Earth Dam

We should discuss the preliminary section of the following items:

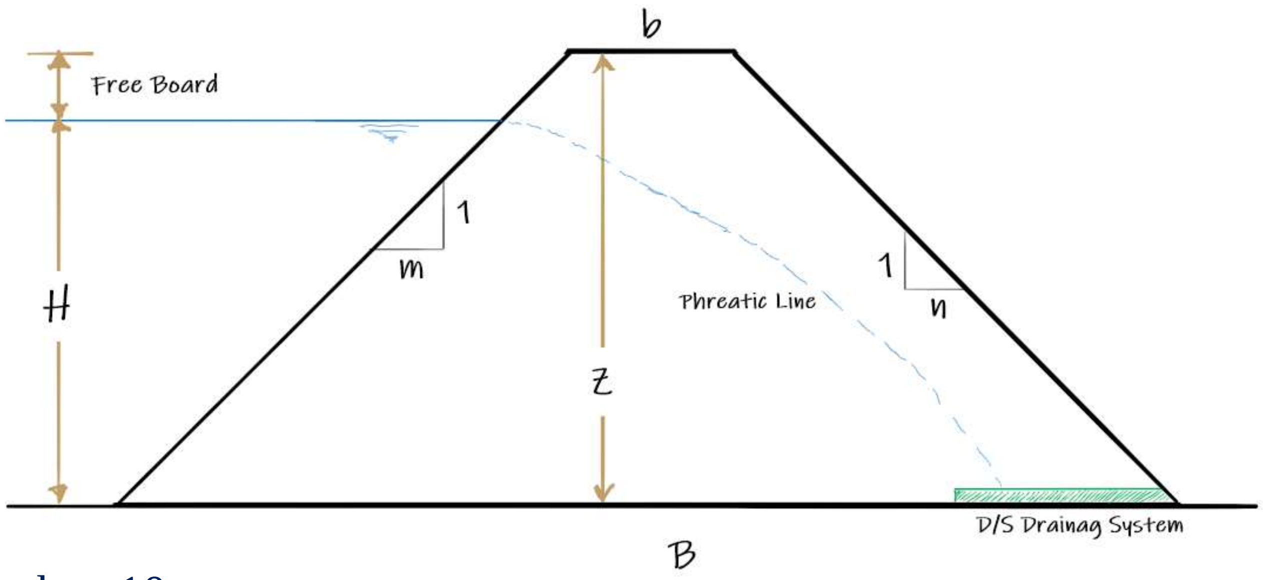
- Top width
- Free board
- Casing of outer shell
- Central impervious core
- Downstream drainage



➢ Top width

The crest width of an earth dam depends on the following:

- ✓ Nature of embankment materials and minimum allowable percolation distance through the embankment of the normal reservoir level
- ✓ Height of the dam
- ✓ Importance of the structure
- ✓ Width of the highway on the top of the dam
- ✓ Protection against earthquake forces



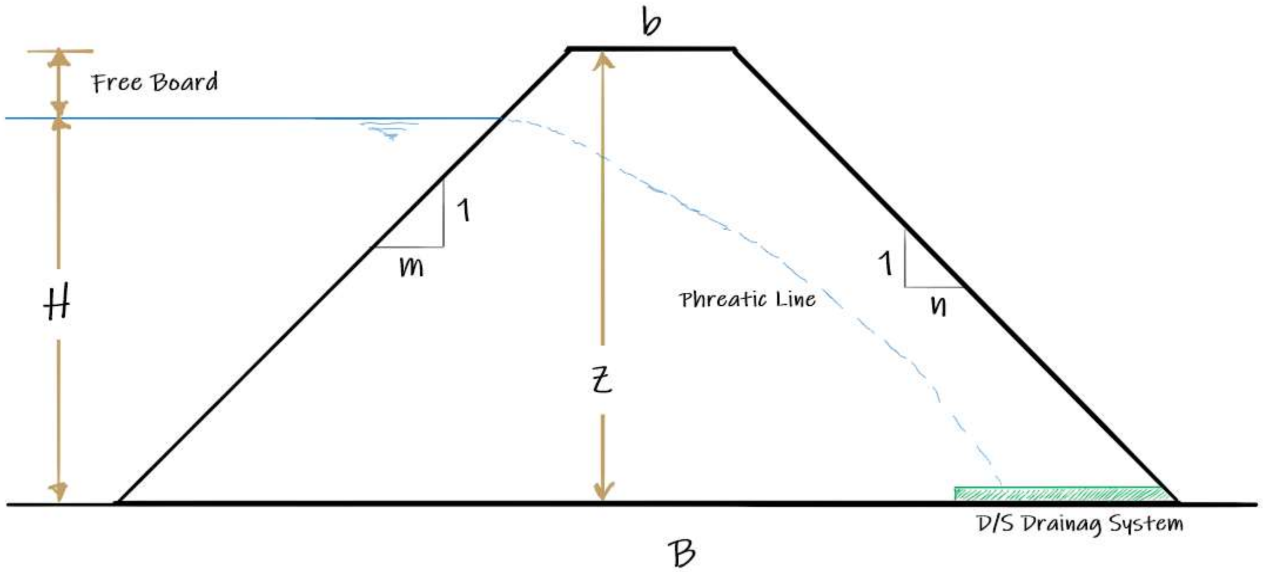
The top width of the dam can be calculated from:

- $b = \frac{Z}{5} + 3$ (Very low dam) less than 10
- $b = 0.55\, Z^{1/2} + 0.2\, Z$ $Z \leq 30\, m$ (10-30 m)
- $b = 1.65(Z + 1.5)^{1/3}$ $Z > 30\, m$

➢ Free board

The free board must be sufficient enough to avoid any possibility of overtopping.

Minimum height of free board for wave action is generally taken equal to (1.5 h_w)



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

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

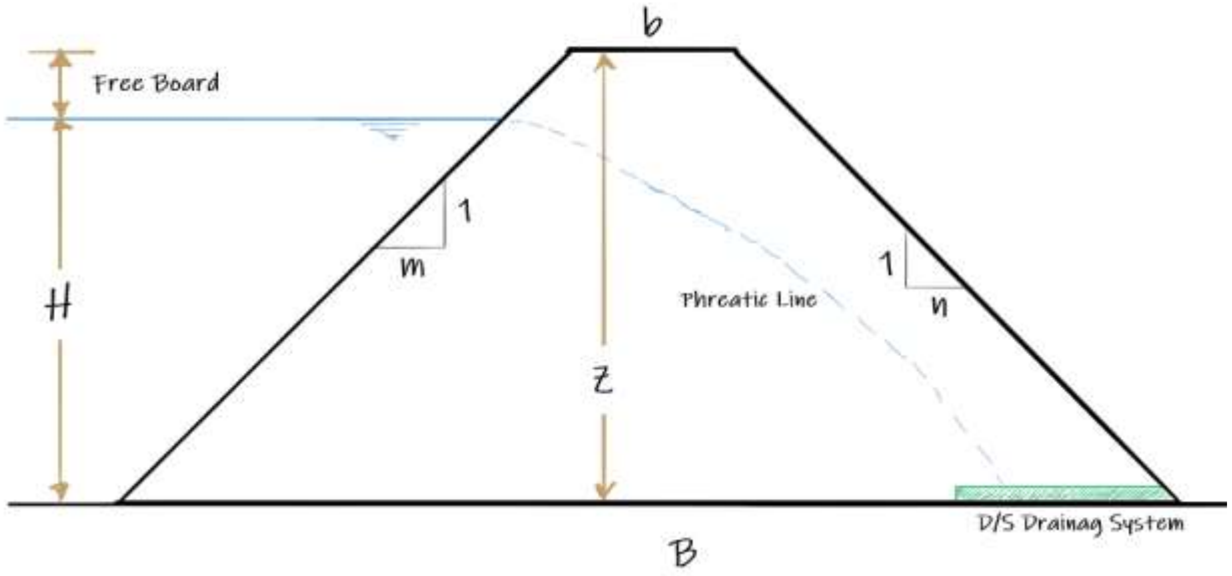
where: V units in km/hr

U.S.B.R Recommendation for free board

Spillway type	Height of the Dam	Min. Free board over Max. W.L.
Uncontrolled (Free spillway)	Any height	2.0 – 3.0 m
Controlled Spillway	Height ≤ 60 m	2.5 m above the top of the gate
Controlled Spillway	Height > 60 m	3.0 m above the top of the gate

➢ Casing of outer shell

The design slope of the upstream and downstream embankment may vary widely depending on the character of the materials available; foundation condition; and the height of the dam. The slopes also depend upon the type of the dam (homogenous, zoned and diaphragm)



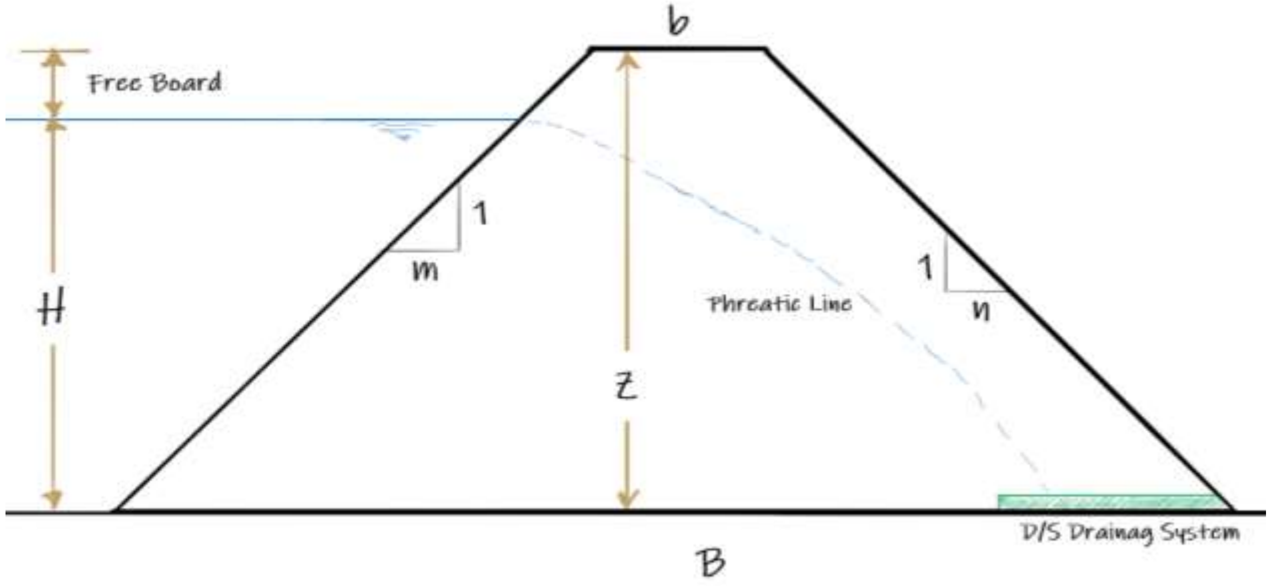
- The upstream slope may vary from 2:1 to as flat as 4:1.
- The downstream slope may vary from 2:1 where a downstream pervious zone is provided to $2\frac{1}{2}:1$ where a downstream is impervious.

Table shown below gives the dimensions of earth according to Terzaghi:

	Soil type	U/S slope	D/S slope
1	Homogeneous well graded material	$2\frac{1}{2}:1$	2:1
2	Homogeneous silty clay or clay a. Height less than 15 m a. Height more than 15 m	 $2\frac{1}{2}:1$ 3:1	 2:1 $2\frac{1}{2}:1$
3	Homogeneous coarse silt	3:1	$2\frac{1}{2}:1$
4	Sand or sand and gravel with clay core	3:1	$2\frac{1}{2}:1$
5	Sand or sand and gravel with R.C. core	$2\frac{1}{2}:1$	2:1

Central impervious core

The width of the core at the crest of the dam should be minimum (3 m). The top level of the core should be at least (1 m) above the maximum water level to prevent seepage by capillary siphoning.

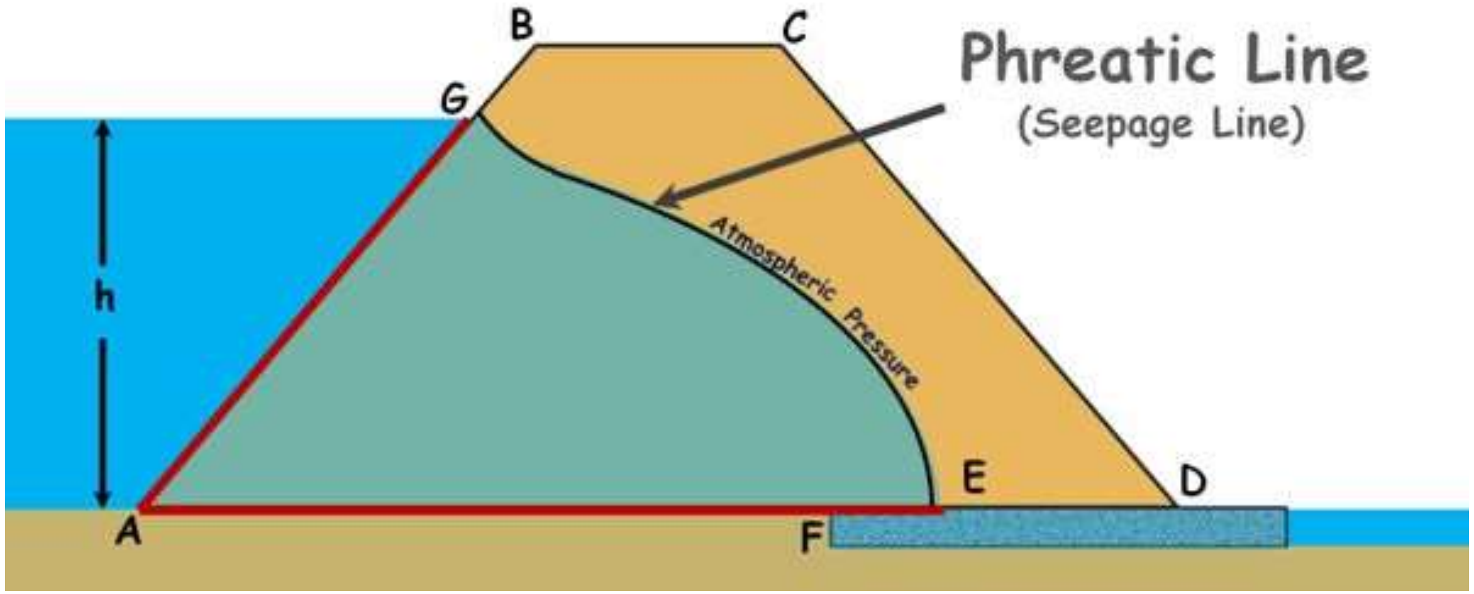


Phreatic line in Earth Dams

The phreatic line is the top of the flow line separating the saturated and unsaturated zones

The phreatic line can be located by:

- Analytical method
- Graphical method
- Experimental method



Experiments have found that the seepage line is pushed down by the filter, and it is very nearly parabolic except near its junction with the U/S face

➢ Graphical Method (Casagrande method)

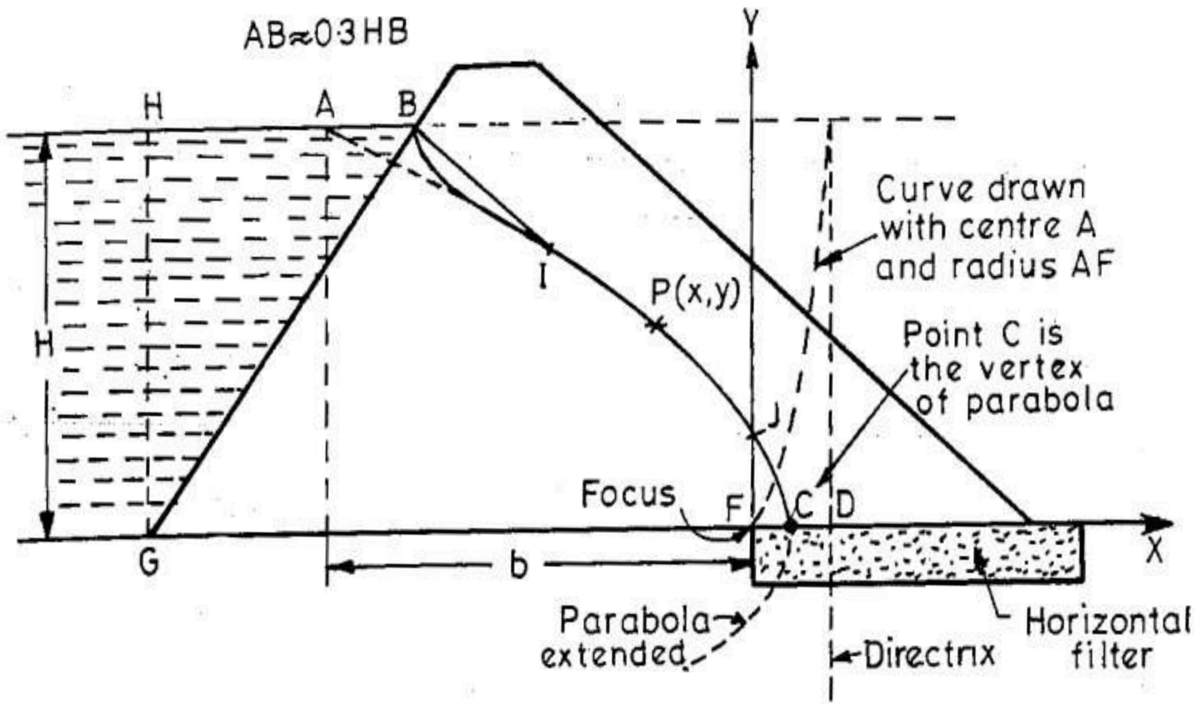
The Casagrande method (*Graphical Method*) assumed the phreatic line to be a base parabola with its focus at (F).

The distance of any point P (x, y) on the parabola from its focus is the same as the distance of that point p (x, y) from a line called the directrix.

Taking the focus (F) as the origin, the equation of the parabola can be written as

$$PF = x + FD$$

$$\sqrt{x^2 + y^2} = x + FD$$



where, the vertical line through D is the directrix. *FD* is the distance of the focus from the directrix, called focal distance, and is generally represented by *S*.

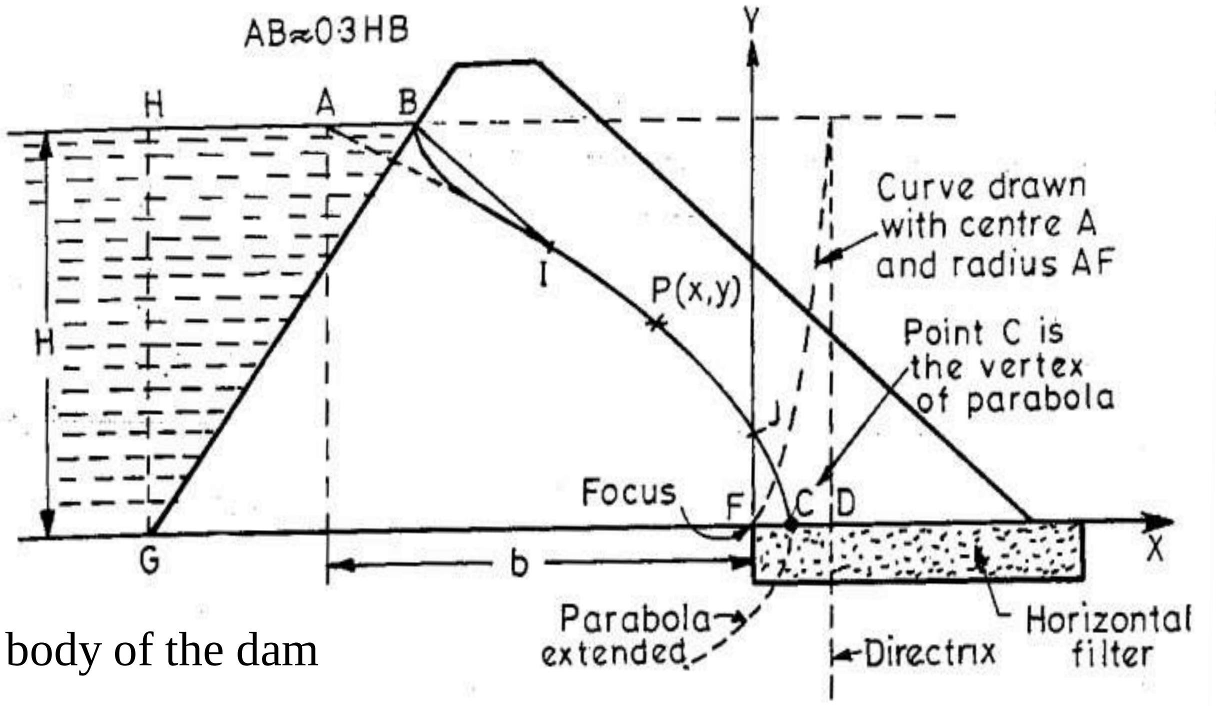
➤ Graphical Method (Casagrande method)

$$\sqrt{x^2+y^2} = x + S$$

$$x^2+y^2 = x^2+2xS+S^2$$

$$y^2 = 2xS+S^2$$

$$\boldsymbol{y = (2xS+S^2)^{1/2}}$$



In order to get an expression for the discharge (q) through the body of the dam

$$q = K\ i\ A = K\ \frac{dy}{dx}\ (y * 1)$$

$$\frac{dy}{dx} = \frac{S}{(2xS+S^2)^{1/2}}$$

$$q = K\frac{S}{(2xS+S^2)^{1/2}}\ (2xS+S^2)^{1/2}$$

$$q = KS$$

where, K is the coefficient of the permeability and S is the focal distance.

- ***Graphical Method (Casagrande method)***

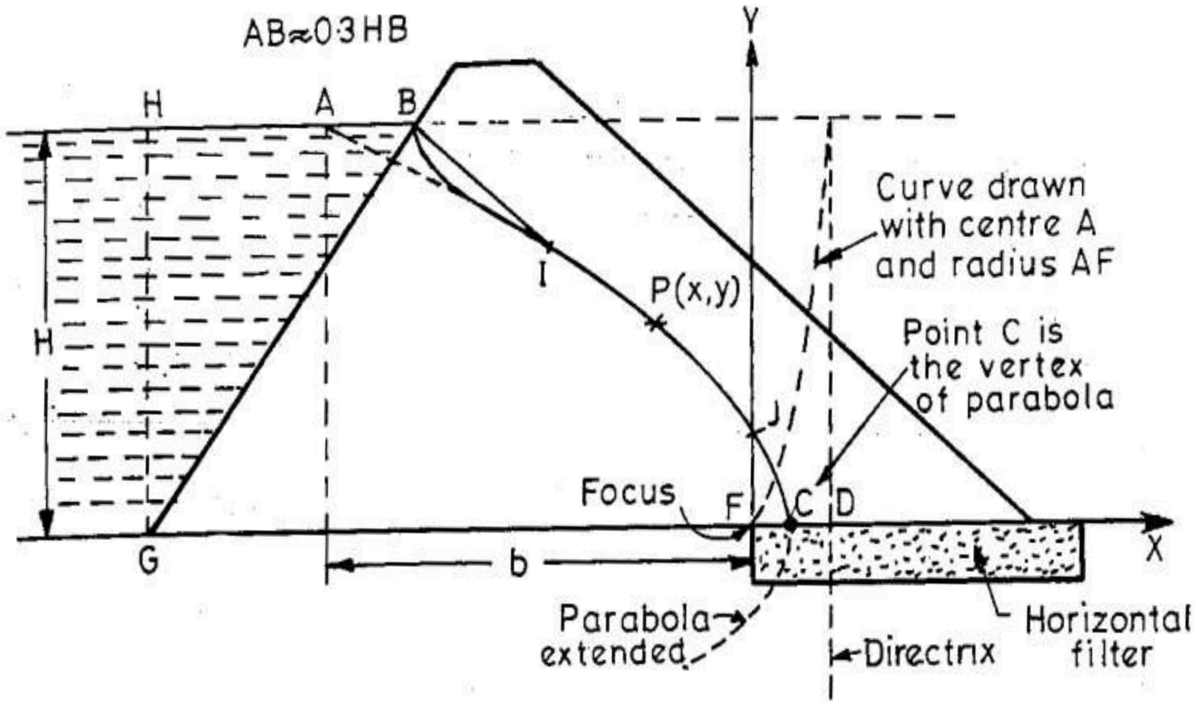
In order to find S

$$\sqrt{x^2 + y^2} = x + S$$

$$S = \sqrt{x^2 + y^2} - x$$, at point A , $x = b$, $y = H$

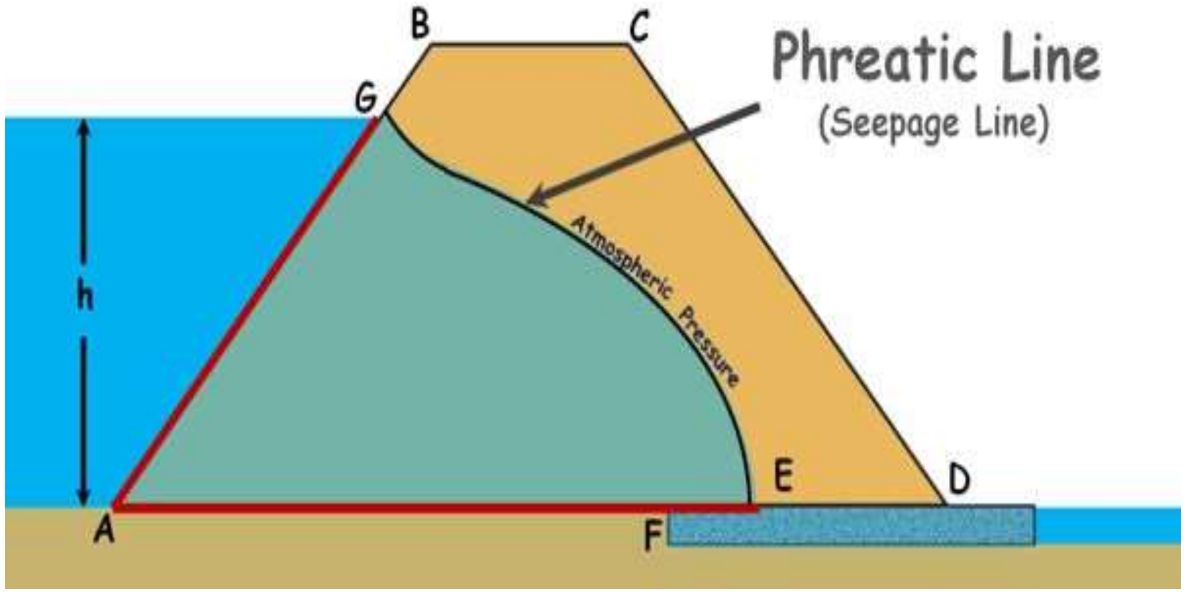
$$S = \sqrt{b^2 + H^2} - b$$

$$b = B - L - 0.7HB$$ L: filter length



➢ The Overall Stability of Earth Dams

$$F.S = \frac{C * B + \sum W\ tan\emptyset}{\sum H} > 1.3$$



where,

$\sum W$ … is the weight of all materials of the dam.

$\sum H$ … is the sum of all Horizontal forces acting on the dam.

B … is the base length of the dam.

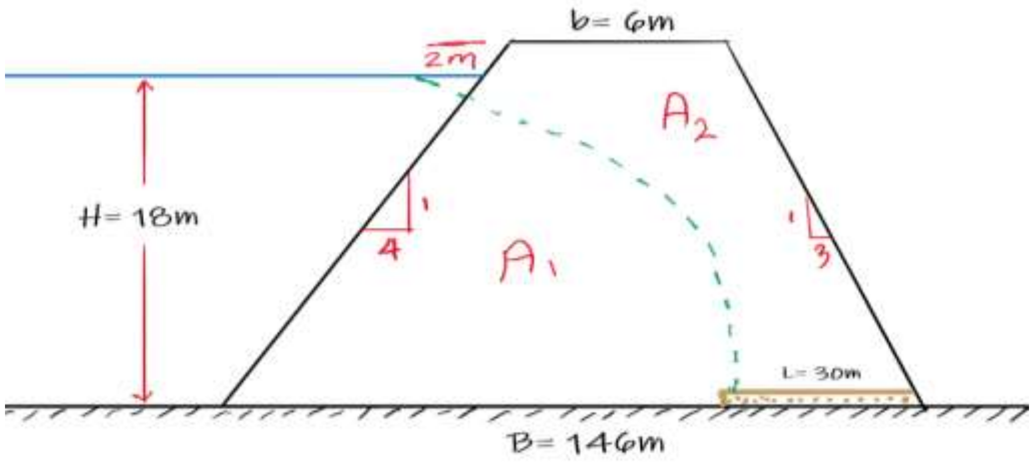
$\emptyset$ ... is the internal friction angle.

C … is the cohesion of soil.

Example: The permeability (K) ($5*10^{-5}$ cm/sec) for the homogeneous section earth dam with a horizontal filter is shown in the figure below. Find

1. The coordinates of the seepage line.
2. The seepage flow per unit width.

If the area under the phreatic line (A_1 = 900 m^2), γ_d of soil = 1.8 ton/m^3, γ_s of soil = 1.2 ton/m^3, $\emptyset$ = 25°, and C= 2.4 ton/m^3, what will be the overall stability of the dam?

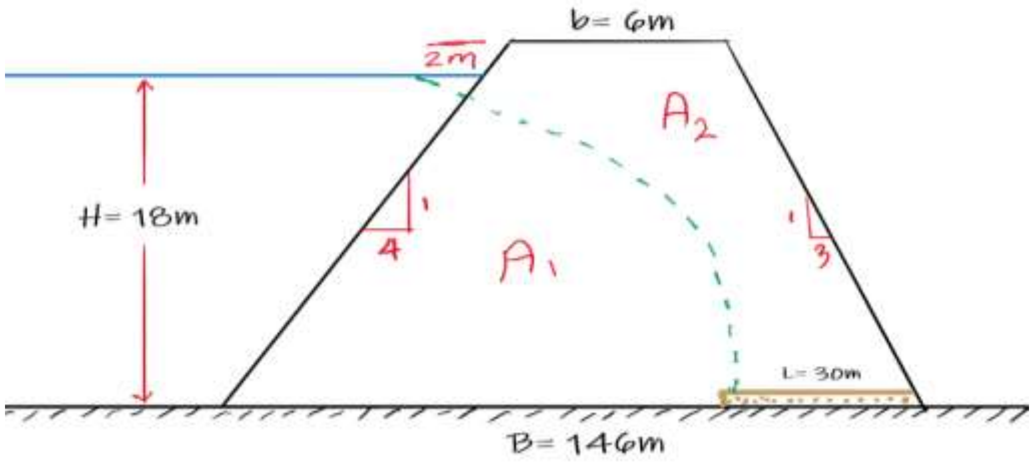


Solution: -

$$y = (2xS + S^2)^{1/2}$$

$$S = \sqrt{b^2 + H^2} - b$$

$$b = B - L - 0.7HB$$



$$HB = 18 * 4 = 72\ m$$

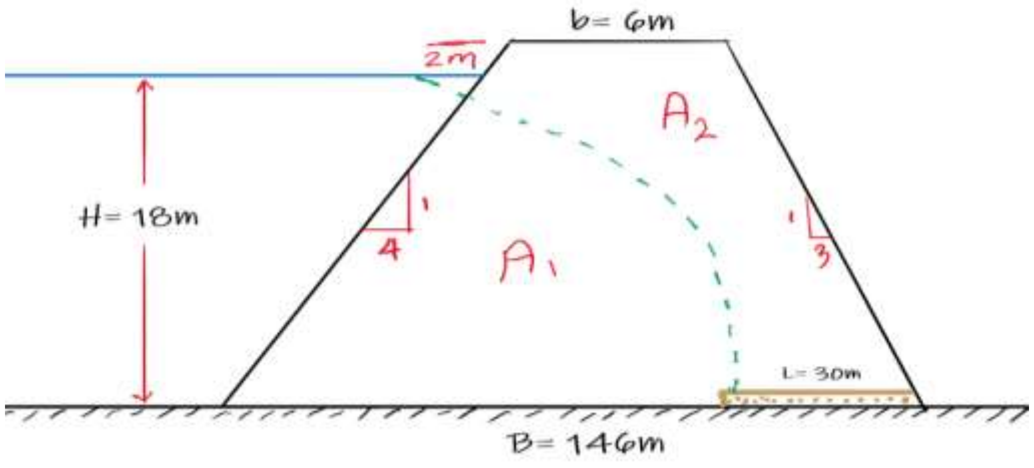
$$b = 146 - 30 - 0.7 * 72 = 65.6\ m$$

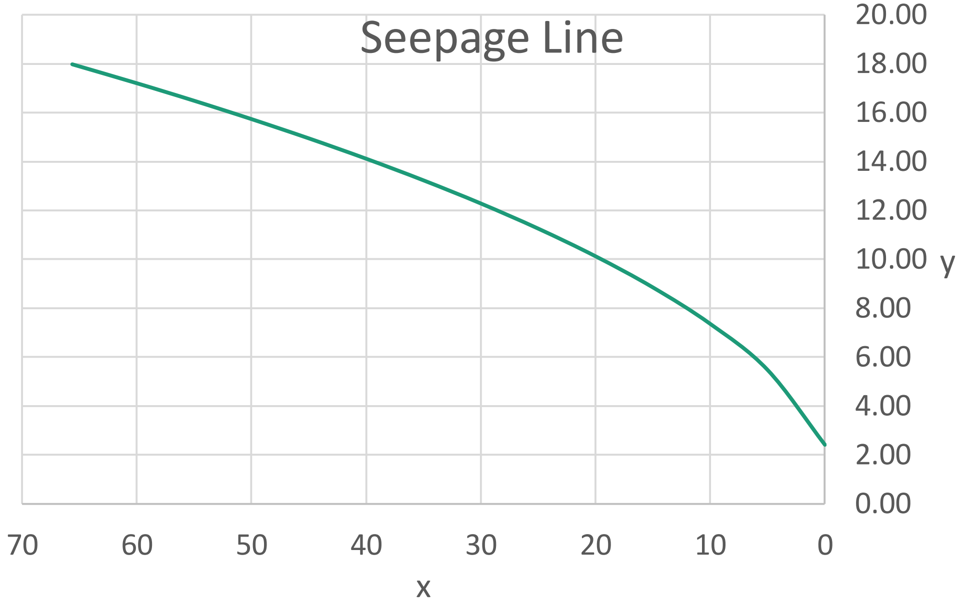
$$S = \sqrt{(65.6)^2 + (18)^2} - 65.5 \qquad \rightarrow S = 2.42\ m$$

$$y = (2xS + S^2)^{1/2}$$

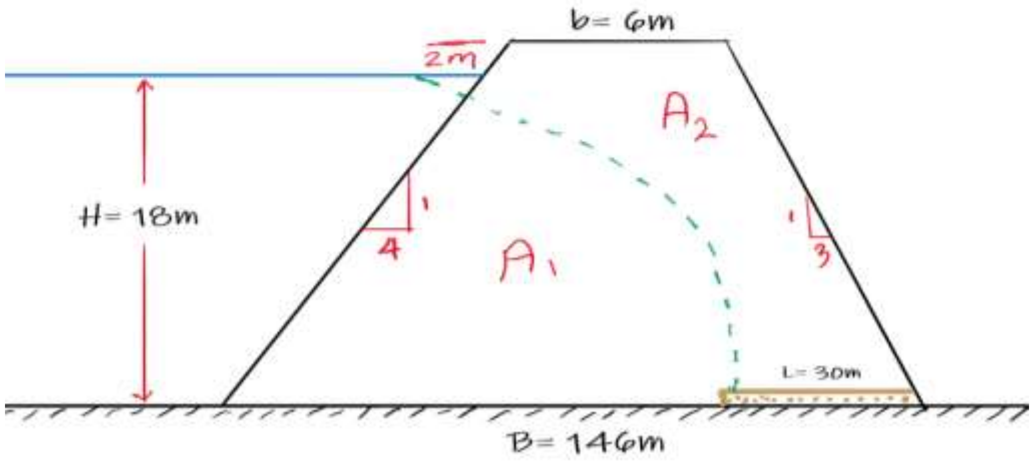
$$y = (2 * 2.42x + 2.42^2)^{1/2} \qquad \rightarrow y = \sqrt{4.84x + 5.85}$$

x	$y = \sqrt{4.84x + 5.85}$
0	2.42
5	5.48
10	7.37
15	8.86
20	10.13
25	11.26
30	12.29
35	13.24
40	14.12
45	14.95
50	15.74
55	16.49
60	17.21
65.6	17.98





The seepage flow per unit width.



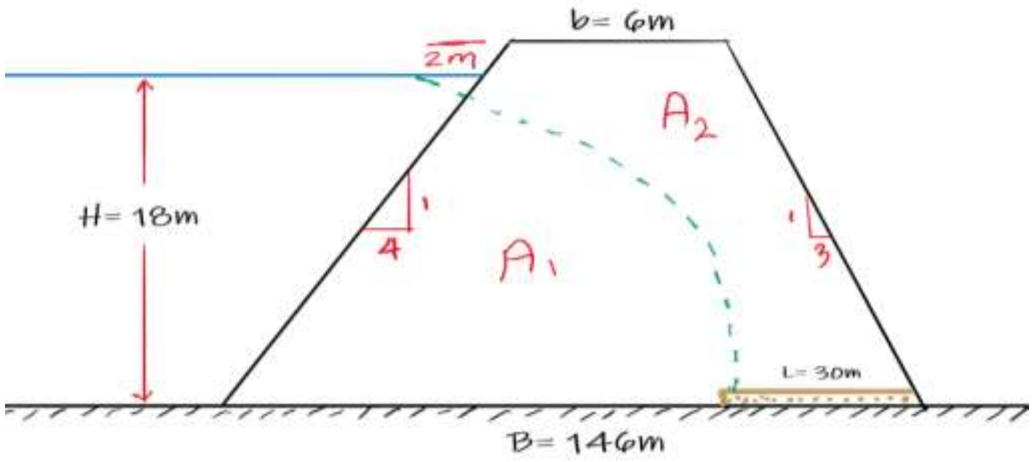
$$q = KS$$

$$\rightarrow \quad q = 5 * 10^{-5} * 10^{-2} * 2.42$$

$$= 12.1 * 10^{-7} \quad m/sec/m$$

To find the overall stability of the dam:-

$$F.S = \frac{C * B + \sum W \tan\emptyset}{\sum H}$$



$$A = \left(\frac{6 + 146}{2}\right) * 20 = 1520\, m^2$$

$$A_2 = A - A_1 \qquad \rightarrow A_2 = 1520 - 900 = 620\, m^2$$

$$W = W_1 + W_2 \qquad = 900 * 1 * 1.2 + 620 * 1 * 1.8 = 2196\, ton$$

$$B = 146\, m$$

$$\sum H = \frac{1}{2}\gamma H^2 \quad = \frac{1}{2} * 1 * (18)^2 = 162\, ton$$

$$F.S = \frac{C * B + \sum W \tan\emptyset}{\sum H}$$

$$F.S = \frac{2.4 * 146 + 2196\, tan25}{162} = 8.45 > 1.3$$

The overall stability of dam is O.K.

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