GATE/ESE

Civil Engineering

Irrigation

Important Formula Notes

IMPORTANT FORMULAS ON IRRIGATION

CHAPTER-1 IRRIGATION TECHNIQUES & QUALITY OF WATER

I. TIME REQUIREMENT

$$t = 2.3 \times \frac{y}{f} \times \log_{10}\left(\frac{Q}{Q - fA}\right)$$

Here,

Q = Discharge through supply ditch.

y = depth of water flowing over the border strip.

f = rate of infiltration of soil.

A = Area of the land strip to be irrigated.

t = time required to cover the given area A.

II. QUALITY OF IRRIGATION WATER

$$C_s = \frac{C.Q}{[Q - (C_u - P_{eff})]}$$

Where,

Q = the quantity of water applied

C_u = consumptive use of water.

P_{eff} = useful rainfall

$C_u - P_{eff}$ = Used up irrigation water

C = Concentration of salt in irrigation water.

C. Q = Total salt applied to the soil with Q amount of irrigation water.

C_s = The salinity concentration of the soil solution

II. PROPORTION OF SODIUM IONS TO OTHER CATIONS (SAR)

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

classification of water based on its SAR value is as follows:

SAR	Type of water
0 – 10	Low sodium water (S_1)
10 – 18	Medium sodium water (S_2)
18 – 26	High sodium water (S_3)
> 26	Very high sodium water (S_4)

CHAPTER 2: SOIL MOISTURE AND PLANT RELATIONSHIP

I. RELATION BETWEEN DUTY AND DELTA

$$\Delta = \frac{8.64\ B}{D}\ m$$

$$\Delta = \frac{864\ B}{D}\ cm$$

B is in days, and D is in ha/m^3

Crop	Delta on the field (cm)
Sugarcane	120
Rice	120
Tobacco	75
Cotton	50
Wheat	40
Barley	30
Maize	25
Fodder	22.5
Peas	15

II. KHARIF-RABI RATIO OR CROP RATIO

It is the ratio (in terms of area) of Kharif season crop to rabi season crop

$$Crop\ ratio = \frac{Area\ irrigated\ in\ Kharif\ season}{Area\ irrigated\ in\ Rabi\ season}$$

III. TIME FACTOR

The ratio of the actual operating period of a canal to the crop period is called the time factor of the canal.

$$Time\ factor\ = \frac{The\ time\ for\ which\ canal\ actually\ runs}{Crop\ period}$$

IV. CAPACITY FACTOR

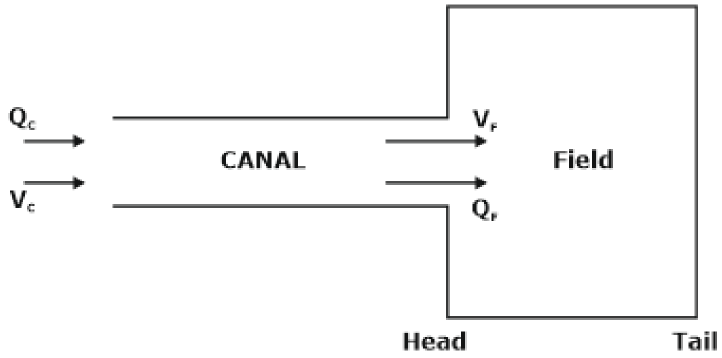
The ratio of mean supply discharge in a canal to its design full capacity is known as the capacity factor.

$$Capacity\ factor = \frac{Mean\ supply\ discharge}{Design\ discharge}$$

V. IRRIGATION EFFICIENCIES

a. Water Conveyance Efficiency (η_c)

This is the ratio of the water delivered into fields from the outlet point of the channel to the water entering into the channel at its starting point.

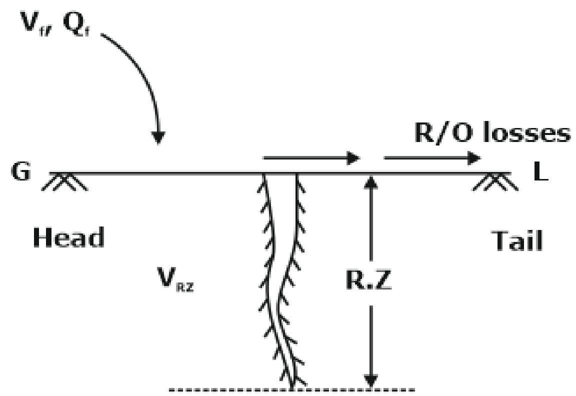


$$\eta_c = \frac{Water\ delivered\ to\ the\ field}{Water\ entering\ the\ canal} = \frac{V_f}{V_c} \times 100 = \frac{Q_f}{Q_c} \times 100$$

It also considers the conveyance or transit losses.

b. Water Application Efficiency (η_a)

It is the ratio of the quantity of water stored in the root zone of the crops to the quantity of water delivered into the field. It may also be called on-farm efficiency, as it considers the water lost in the farm.



$$\eta_a = \frac{water\ stored\ in\ the\ root\ zone}{water\ delivered\ to\ the\ field} = \frac{V_{RZ}}{V_f} \times 100$$

Also,

$$V_{RZ} = V_f - \text{Run off losses.}$$

c. Water Storage Efficiency (η_s)

It is the ratio of the water stored in the root zone during irrigation to the water needed in the root zone before irrigation.

$$\eta_s = \frac{Water\ actually\ stored\ in\ the\ root\ zone}{Water\ needed\ in\ the\ root\ zone\ for\ reaching\ field\ capacity} = \frac{V_{RZ}}{V_{R_{RZ}}} \times 100$$

$V_{R_{RZ}}$ = volume of water required in the root zone

d. Water Use Efficiency(η_u)

It is the ratio of the water beneficially used, including leaching water, to the quantity of water delivered. Mathematically, it can be expressed as follow.

$$\eta_u = \frac{water\ beneficially\ used\ in\ irrigation}{Quantity\ of\ water\ delivered\ to\ field} = \frac{V_u}{V_f} \times 100$$

here,

V_u = volume of water used by the plant

V_f = volume of water supplied to the field.

e. Water Distribution Efficiency (η_d)

The effectiveness of irrigation may also be measured by its water distribution efficiency, which is defined below.

$$\eta_d = \left(1 - \frac{d}{D}\right) \times 100$$

D = Mean depth of water stored during irrigation.

d = average of the absolute values of deviations from the mean.

VI. CONSUMPTIVE USE OR EVAPOTRANSPIRATION (C_U)

Consumptive use for a particular crop can be defined as the total amount of water used in transpiration and evaporation from adjacent soils or plant leaves at any specified time.

$$C_u = \frac{T + E}{B} \; mm/day$$

T = transpiration

E = Evaporation

B = Base period

Values of monthly consumptive use are used to determine the irrigation requirement of the crop.

Frequency of irrigation $= \frac{depth\ of\ root\ zone}{Consumptive\ use} = \frac{d_{rz}}{C_u} \left(\frac{mm}{\frac{mm}{day}}\right)$

VII. DETERMINATION OF CONSUMPTIVE USE

a. Direct Method

1.Tank Lysimeter method

2.Field Experimental Plots

3.Inflow outflow studies: The consumptive use is obtained by studying inflow and outflow in a certain area.

$$E = I + P - O + G_s - G_e$$

Where,

E = Consumptive use

I = Total inflow

P = Precipitation in that area

O = Total outflow

G_s = Groundwater storage in the starting

G_e = Groundwater storage at the end of the year

b. Indirect Method

1.Blaney – Criddle Formula: It states that the monthly consumptive use is given as

$$Cu = \frac{k.p}{40} [1.8t + 32]$$

k = crop factor, it is determined by experiment for each crop, under the environmental conditions of the particular area.

t = Mean monthly temperature is °C

p = monthly percent of annual daylight hours during the period.

2.Hargreaves Class Pan Evaporation Method: Evapotranspiration is related to pan evaporation by a constant k called consumptive use coefficient. The formula can be written as

$$\frac{Evapotranspiration\ (Cu)}{Pan\ Evaporation\ (E_p)} = k$$

$E_p$can be measured experimentally as well as empirically.

3.Penman Equation: This equation is derived by combining the energy balance and mass transfer approach of the computation of evaporation and transpiration, respectively. It is given as,

$$E_t = \frac{AH_n + E_a\gamma}{A + \gamma}$$

E_t = Daily Potential evapotranspiration

A = Slope of the saturation vapour pressure vs temperature curve at the mean air temperature

H_n= Net incoming solar radiation expressed in mm of evaporable water per day

E_a = A parameter including wind velocity and saturation deficit

γ = psychrometric constant

VIII. IRRIGATION REQUIREMENTS

a. Effective rainfall (P_{eff}): It is that portion of natural rainfall that falls during the crop's growth period and is available for the evapotranspiration need of the crop.

b. Consumptive Irrigation Requirement (CIR): It is that part of consumptive use which has to be supplied by the provision of irrigation, and mathematically it is expressed as follows.

$$CIR = C_u - P_{eff}.$$

c. Net Irrigation Requirement (NIR): It takes into consideration the CIR as well as leaching requirement (i.e. to reduce the salinity of soil in the root zone).

Mathematically, it is expressed as follow.

$$NIR = CIR + LR$$

Where, LR = Leaching requirement of soil

d. Field Irrigation Requirement (FIR): It considers the surface runoff losses occurring over the field and is expressed as follows.

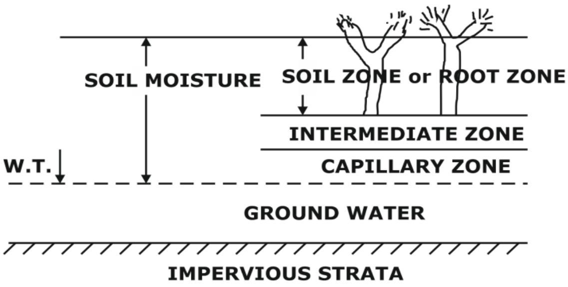
$$FIR = \frac{NIR}{\eta_a}$$

Here, η_a = surface runoff losses.

e. Gross Irrigation Requirement (GIR): It considers the conveyance and transmission losses occurring in a canal and is expressed as follows.

$$GIR = \frac{FIR}{\eta_c}$$

CHAPTER 3: WATER REQUIREMENTS OF CROP



I. FIELD CAPACITY

The proportion of water apart from gravity water retains on the surfaces of soil grains by molecular attraction and by loose chemical bonds (i.e. adsorption). This water cannot be easily drained under the action of gravity and is known as field capacity.

$$FC = \frac{Weight\ of\ water\ in\ certain\ volume\ of\ soil}{Weight\ of\ same\ volume\ of\ drysoil} \times 100$$

$$d_{w_f} = \frac{\gamma_d}{\gamma_w} \times d \times FC$$

d_{wf}= depth of water in the soil

d = depth of root zone

γ_d = Dry density of soil

γ_w = Dry unit weight of soil

II. PERMANENT WILTING POINT

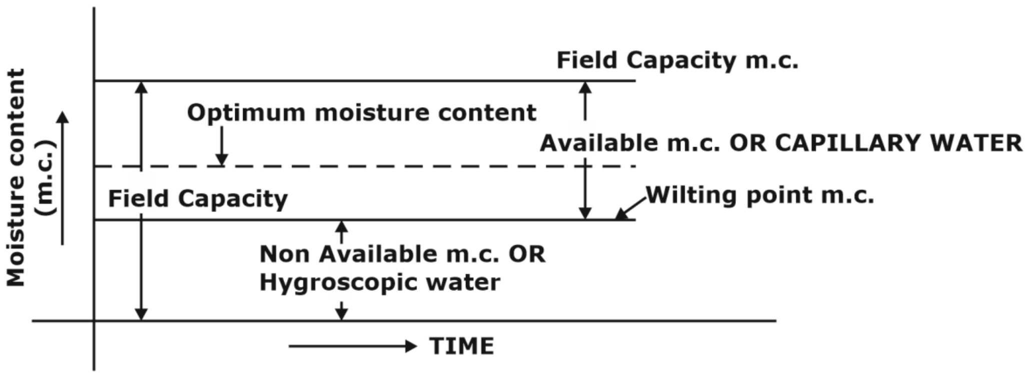
Water content in the root zone below which plant can no longer extract sufficient water for its growth and wilts up.

$$Available\ moisture = Field\ Capacity - Permanent\ wilting\ point$$

III. OPTIMUM MOISTURE CONTENT

The optimum level up to which the soil moisture can be allowed to be depleted in the root zone without fall in the crop yield represents the OMC.

IV. ANALYSIS OF FREQUENCY OF IRRIGATION

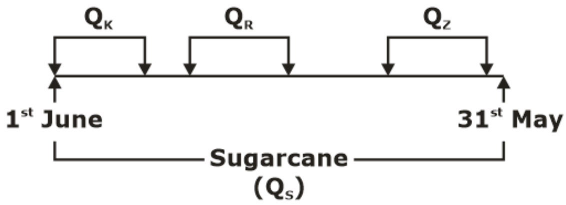


Maximum storage capacity or available moisture

$$= \frac{\gamma_d}{\gamma_w} \cdot d \left[\frac{\text{Field capacity moisture content}}{100} - \frac{\text{Wilting poin moisture content}}{100} \right]$$

CHAPTER 4: DESIGN OF LINED & UNLINED CANALS

I. CALCULATION OF DESIGN CAPACITY OF A CANAL



Q_K = Discharge required for Kharif season

Q_R = Discharge required for Rabi season

Q_Z = Discharge required for Zaid season

Q_S = Discharge required for sugarcane

$$\text{Design discharge} = Q_d = \text{Maximum of} \begin{cases} Q_K + Q_S \\ Q_R + Q_S \\ Q_Z + Q_S \end{cases}$$

II. DESIGN OF ALLUVIAL CANAL

a. Kennedy Theory

Design Steps:

Step 1: For a given discharge, assume a trial depth and find the critical velocity as per the following expression.

$$v_0 = nC_1 y^{C2}$$

The first depth can be assumed as per the given discharge value and, as suggested by Kennedy.

Step 2: for the given Discharge and an above-calculated v_0, calculate the area required as following.

$$A = \text{Area required} = \frac{\text{Discharge}}{\text{Velocity}} = \frac{Q}{V_0}$$

Step 3: Find the dimensions of the channel by assuming it to be a trapezoidal channel with the side slope of $\frac{1}{2}H : 1\ V$.

Step 4: Calculate the hydraulic radius as following

$$\text{Hydraulic radius} = R = \frac{\text{Area}}{\text{Parameter}} = \frac{A}{P}$$

Step 5: Using the above value of R, calculate the actual mean velocity of flow by either using Chezy's equation or manning's equation as following

$$V = C\sqrt{R.S} \quad \text{(Chezy's formula)}$$

Here, C = Chezy's constant

R = hydraulic radius

S = slope of the canal.

$$V = \frac{1}{n}R^{2/3}S^{1/2} \text{ (Manning's formula)}$$

$$C = \frac{\frac{1}{n} + 23 + \frac{0.00155}{S}}{1 + \left(23 + \frac{0.00155}{S}\right)\frac{n}{\sqrt{R}}} \qquad \text{(Kutter's formula)}$$

n = Kutter's rugosity coefficient.

If the actual mean velocity value calculated above equals the critical velocity of step 1, the design is okay; else, repeat the above steps for the suitable trial depth.

Following is the table to assume first trial depth depending upon the given discharge value.

Q(m^3/sec)	Y(m)
0 – 20	1.0
20 – 40	2.0
40 – 80	2.5
80 – 100	3.0
> 100	3.5

- If the channel's bed slope value is not given, it can be taken as s = 1 in 2500 to 1 in 5000.
- If the value of Manning's coefficient is not given, it can be assumed as per the following range.

n: manning's constant	Material
0.022 – 0.025	Good Earthen channel
0.025 – 0.030	Poor Earthen channel
0.015 – 0.018	Concrete lined channel

b. Lacey's Theory

Design procedure

Step 1: The velocity of flow is calculated as following.

$$v = \left(\frac{Qf^2}{140}\right)^{1/6} \text{ m/s}$$

Here, f = silt factor

$$f = 1.76\sqrt{d}$$

d = average size (diameter) of silt particles in mm.

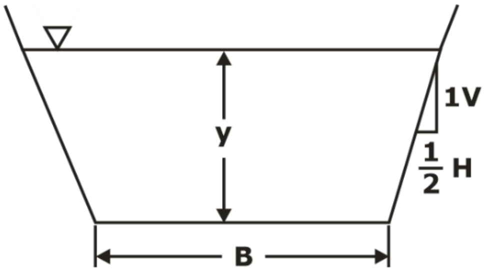
Step 2: Find the hydraulic radius using the following relation

$$R = \frac{5}{2}\frac{v^2}{f}$$

Step 3: For the given Discharge, calculate the area required as following

$$A_{req} = \frac{Q}{v_0}$$

Step 4: For an assumed cross-section of trapezium of side slope, $\frac{1}{2}H:1V,$ express the value of area required in forms of B and y.



Step 5: Calculating the wetted perimeter for the known Discharge as following:

$$P = 4.75\sqrt{Q}$$

Now, express the known value of P in terms of B and y.

Step 6: Calculate the value of bed slope for known value if Discharge as per the following.

As per Lacey's theory, the scour depth can be calculated for the following cases.

Case 1: For Wide channel (Regime channel, P ≃ B).

R_r: Normal regime scour depth

$$R_r = 0.473\left(\frac{Q}{f}\right)^{1/3}$$

Here, Q = Flood discharge.

Case 2: For normal channel (R′$_r$: Normal scour depth)

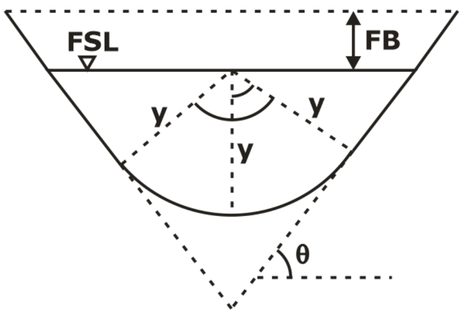
$$P_r' = 1.35\left(\frac{q^2}{f}\right)^{2/3}, m$$

q = discharge/unit width.

III. DESIGN OF LINED CANAL

a. Triangular section with round bottom

This type of cross-section is to be used when Discharge through the lined canal is in the range of Q ≤ 55 m^3/sec.



FB : Free board $\begin{cases} = 0.75 \text{ m for main canal} \\ = 0.60 \text{ m for branck canal} \end{cases}$ FSL: Full supply level

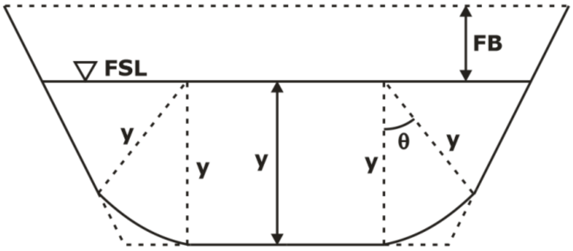
$\Rightarrow A_f = y^2(\theta + \cot\theta)$

$\Rightarrow P = 2y(\theta + \cot\theta)$

$\Rightarrow \frac{A}{P} = R \Rightarrow \boxed{R = \frac{y}{2}}$

b. Trapezoidal section with round corner

It is suitable for the canal having the Discharge, $Q > 55\ m^3/sec$



Area of flow = $A_f = By + y^2(\theta + \cot\theta)$

$P = B + 2y\ (\theta + \cot\theta)$

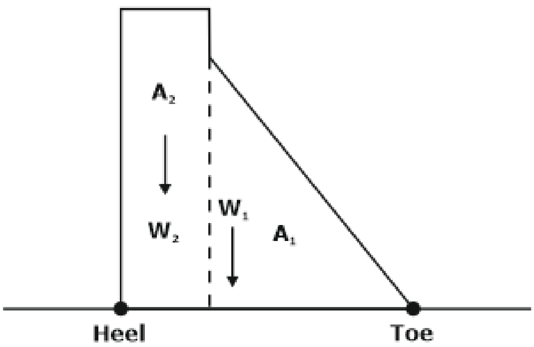
Lining Material	Permissible v_f
Cement concrete	2.5 m/s
Tile (Burn clay)	1.8 m/s
Stone (Boulder)	1.5 m/s

CHAPTER 5: GRAVITY DAM & SPILLWAYS

I. FORCES ACTING ON GRAVITY DAM

a. Self-weight

The self-weight of the dam is the major retarding Force that acts on the dam. It acts through the centre of gravity of the dam.



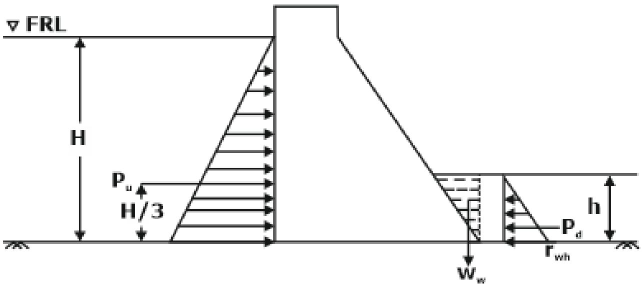
$\Rightarrow$ Total weight = $\gamma_c (A_1 + A_2)$

$$\Rightarrow W_T = \gamma_c \sum_{i=1}^{n} A_i$$

Where,

γ_c = specific unit weight of concrete

b. Force due to Water Pressure



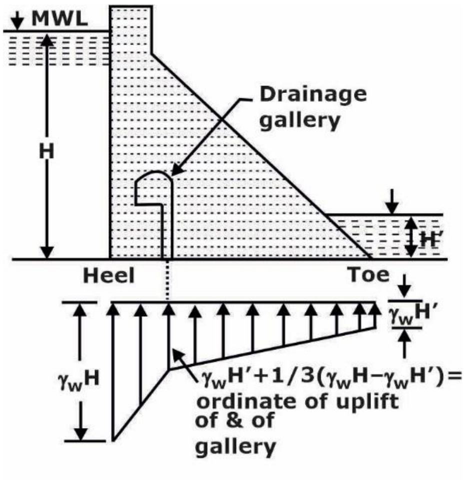
Pressure at upstream: $P_u = \frac{\gamma_w H^2}{2}$

Which is acting at a distance of H/3 from the base of the dam.

Pressure at downstream: $P_d = \frac{\gamma_w h^2}{2}$

Acting at a distance of h/3 from the base of the dam.

c. Uplift pressure



Uplift Pressure

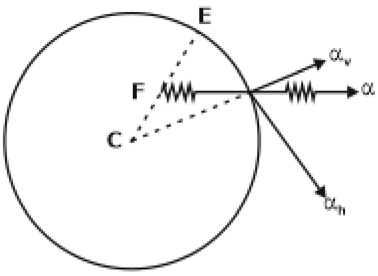
d. Earthquake force

Earthquake wave may move in any direction, and for design purposes, it has to be released in vertical and horizontal components. Hence, two acceleration, i.e. one horizontal acceleration (α_h) and one vertical acceleration (α_v) are induced by an earthquake. The value of the basic seismic coefficient (α_o) according to the zone is given below.

Seismic zones	Value of α_o
Zone I	0.01
Zone II	0.02

Zone III	0.04
Zone IV	0.05
Zone V	0.08

The seismic force can be analysed as shown below:



C: Centre of Earth

F: Focus/Hypo centre of Earthquake

E: Epi-centre

Generally, the value of vertical acceleration is 75% of the horizontal acceleration.

$$\alpha_v = 75\% \text{ of } \alpha_h$$

Where, $\alpha_h = k.g$

k: seismic co-efficient, which is equal to

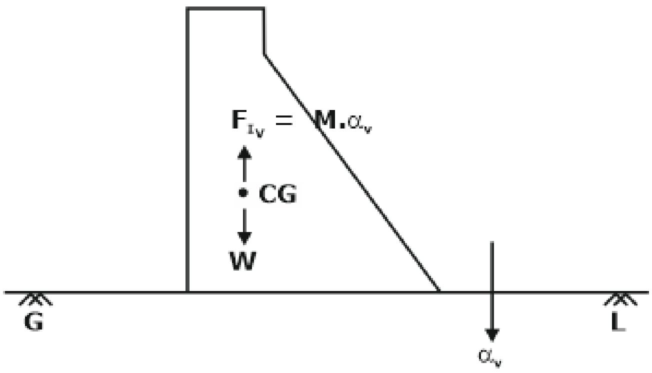
$$k = \beta \, I \, \alpha_o$$

Where,

β: soil foundation system factor (1 for gravity dams)

I: importance factor (3 for gravity dams)

1. Effect of α_v (Vertical acceleration)



α_v can act in an upward direction also, but we are taking for worst condition.

$$w' = w - F_{I_v}(\uparrow)$$

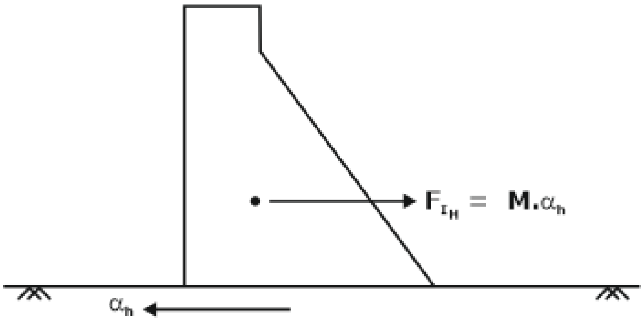
$$\Rightarrow w' = w - M.\alpha_v$$

$$\Rightarrow w' = w - \frac{w}{g}\alpha_v$$

$$\Rightarrow w' = w\left(1 - \frac{\alpha_v}{g}\right)$$

2. Effect of α_h (horizontal acceleration)

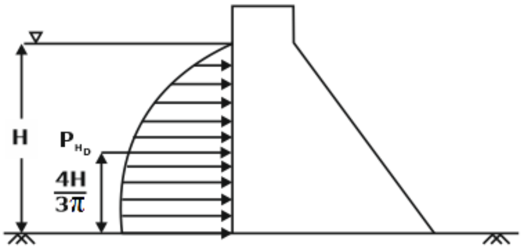
Development of F_{I_H}:



$$F_{I_H} = \frac{w}{g} \times k.g$$

$$\Rightarrow F = kw\ (\rightarrow)$$

Development of hydrodynamic Force:



$P_{H_D} = 0.555k\gamma_w H^2$, Acting at $\frac{4H}{3\pi} = 0.424H$ from base.

e. Wave pressure

Waves are generated on the reservoir's surface by the blowing winds, which causes pressure toward the downstream side.

Wave pressure depends upon the wave height. The equation may give wave height.

$h_w = 0.032\sqrt{V.F} + 0.763 - 0.271(F)^{3/4}$ for F < 32 km.

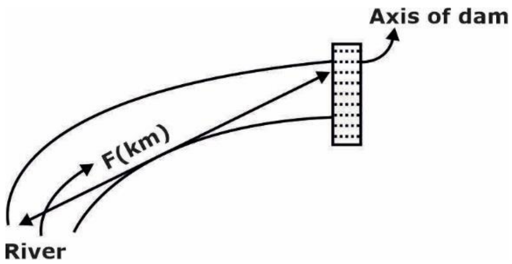
$h_w = 0.032\sqrt{V.F}$ for F > 32 km

Where,

h_w = height of the water from the top of the crest to the bottom of the trough in meters.

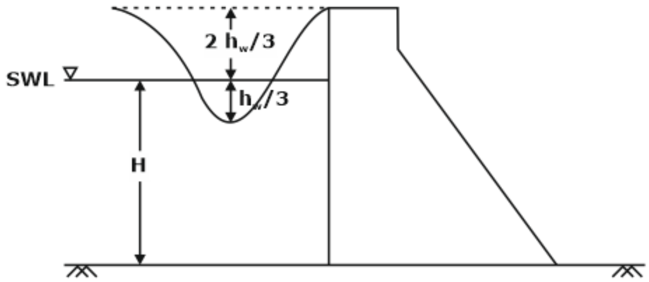
V = wind velocity in km/hr

F = fetch or straight length of a water expanse in km.



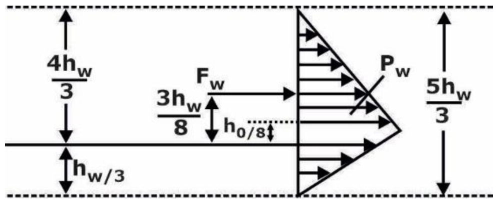
The maximum pressure intensity due to wave action may be given by

$p_w = 2.4\ \gamma_w h_w$ and acts at $\frac{h_w}{2}$ meters above the still water surface.



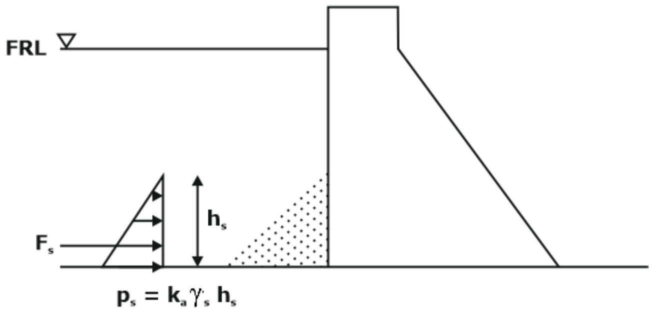
SWL = Still water level.

h_w = height of the wave.



$Fw = 2\gamma_w h_w^2$ @ 3 h_w/s above SWL.

f. Silt Pressure



p_s = maximum active silt pressure

k_a = active silt pressure coefficient = $\frac{1-\sin\theta}{1-\sin\theta} = tan^2(45-\phi/2)$

ϕ = angle of internal friction of soil.

γ_s = submerged unit weight of silt = $\gamma_{sat} - \gamma_w$

h_s = height of silt load

$$F_s = \frac{k_a\,\gamma_s\,h_s^2}{2}$$, Acting at $\frac{h_s}{3}$ from base.

In any absence of any data, silt pressure can be taken as

$F_s = \frac{1}{2} 360\ h_s^2$ in kg.f

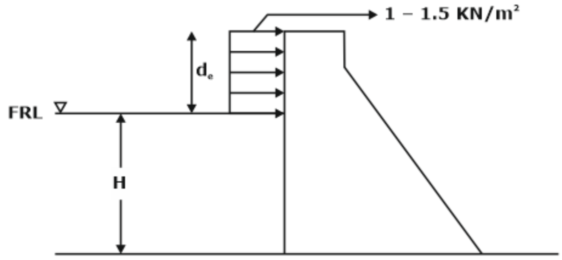
g. Ice pressure

- The ice formed on the reservoir's water surface in cold countries may sometimes melt and expand.
- The dam face then resists the thrust exerted by the expanding ice.

- The magnitude of this Force varies from 250 to 1500 kN/m^2 depending upon temperature variation. On average, a value of 500 kN/m^2 may be allowed under ordinary conditions.

h. Wind pressure

- Its value is taken as 1 – 1.5 kN/m^2 of the exposed area

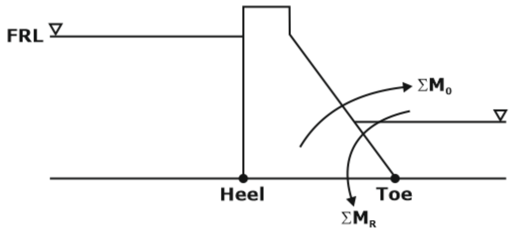


$$F_{wind} = 1.5 \times d_c \times 1 \text{ kN} \ @ \left(H + \frac{d_c}{2}\right) \text{ from base.}$$

II. MODES OF FAILURE FOR A GRAVITY DAM

a. Overturning:

- If the resultant of all the forces acting on a dam, any of its sections passes outside the toe, the dam shall rotate and overturn about the toe.
- The ratio of the righting moments about the toe to the overturning moments about the toe is called the factor of safety against overturning.



For no overturning about the toe, $\Sigma M_R \geq \Sigma M_o$

$$\Rightarrow \frac{\Sigma M_R}{\Sigma M_o} \geq 1$$

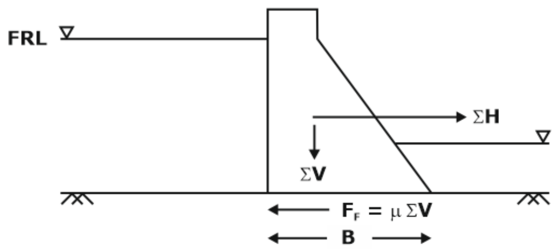
$$FOS = \frac{\Sigma M_R}{\Sigma M_o} \geq 1$$

For design condition,

$$FOS = \frac{\Sigma M_R}{\Sigma M_o} \simeq 1.5$$

b. Sliding:

- Sliding (or shear failure) will occur when the net horizontal Force above any plane in the dam or at the dam's base exceeds the frictional resistance developed at that level.



For no sliding failure, resisting Force ≥ sliding Force

$$\mu\Sigma V \geq \Sigma H$$

$$FOS_{sliding} = \frac{\mu\Sigma V}{\Sigma H} \geq 1$$

- The shear friction factor is used to check the stability of a dam against sliding when the bond strength of concrete is also considered. It is given by

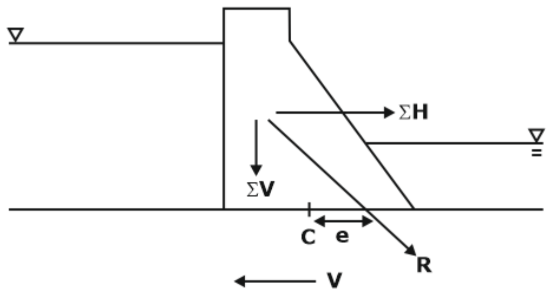
$$SFF = \frac{\text{Resisting Force}}{\text{Sliding Force}} = \frac{\mu\Sigma V + q \times B \times 1}{\Sigma H}$$

q = bond strength of concrete (kN/m^3)

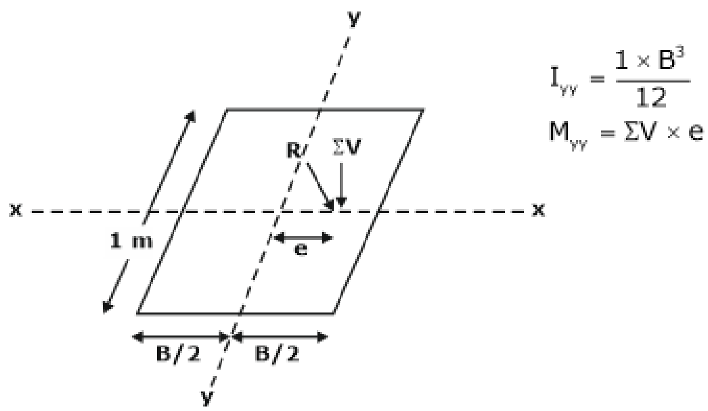
- For the same FOS against the sliding mode of failure, the weight of concrete used in the second case will be less thanthe first case, and therefore the second case gives us an economical design.

c. Crushing/compression mode of failure

- A dam may fail by the failure of its materials, i.e. the compressive stresses produced may exceed the allowable stresses, and the dam material may get crushed.



Considering base area for 1 m length of dam (B x 1)

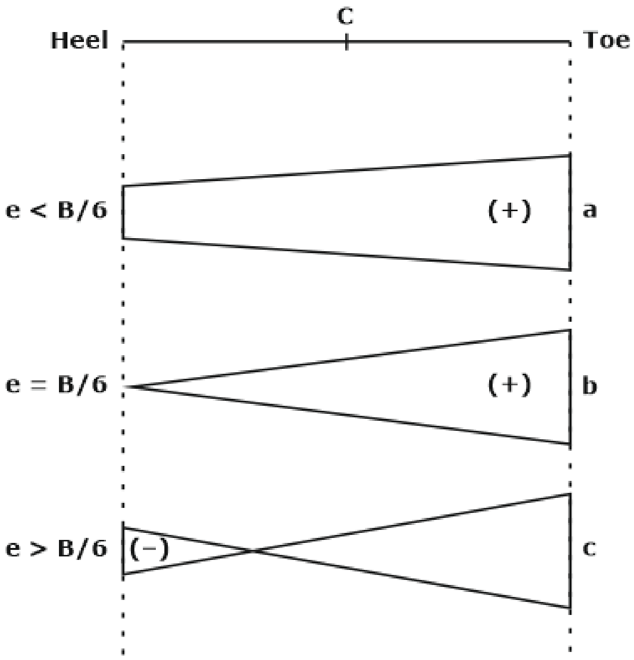


$$\left(\sigma_{V_{max}}\right)_{toe} = \frac{\Sigma V}{B}\left(1 + \frac{6e}{B}\right)$$

And, minimum compressive stress will be at the heel of the section, i.e. x = -B/2

$$\left(\sigma_{V_{\min}}\right)_{Heel} = \frac{\Sigma V}{B}\left(1 - \frac{6e}{B}\right)$$

Now, the resultant stress on base width will have the following distribution depending upon the value of e.

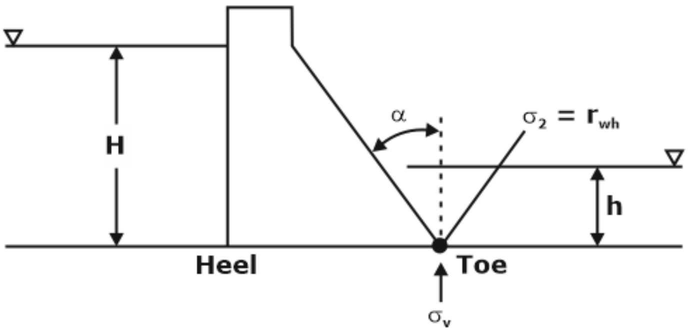


e = eccentricity of the resultant force from the centre of the base.

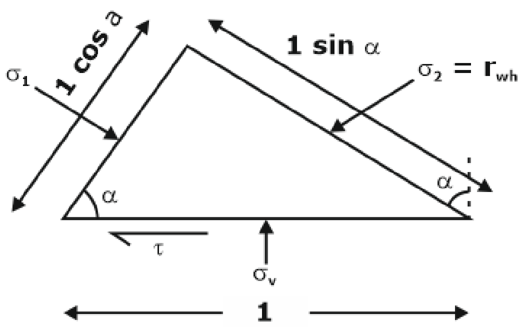
ΣV = total vertical force

B = base width.

Now, analysing a stress element @ Toe



Taking a small triangular section at the toe, the free body diagram of the stresses will be



For no crusting,

$$\sigma_1 \le f\left(=\frac{\sigma_y}{Fos}\right)$$

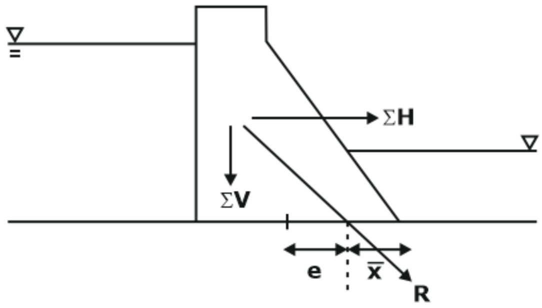
f = failure strength of concrete.

$$\Rightarrow \tau = (\sigma_v - \sigma_2)\tan\alpha.$$

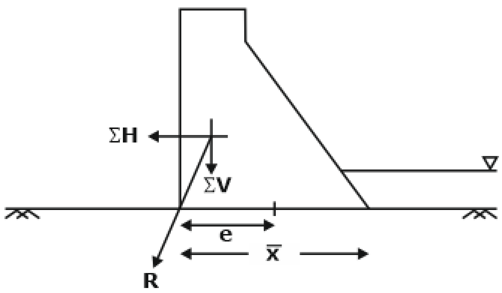
d. Tension/tensile mode of failure

$$\left(\sigma_{V_{\min}}\right)_{Heel} = \frac{\Sigma V}{B}\left(1 - \frac{6e}{B}\right)$$

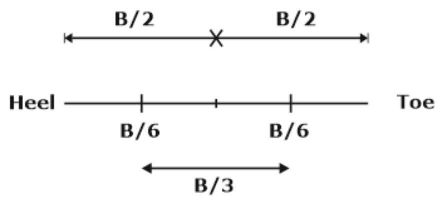
Case1: When the reservoir is full



Case 2: When the reservoir is empty

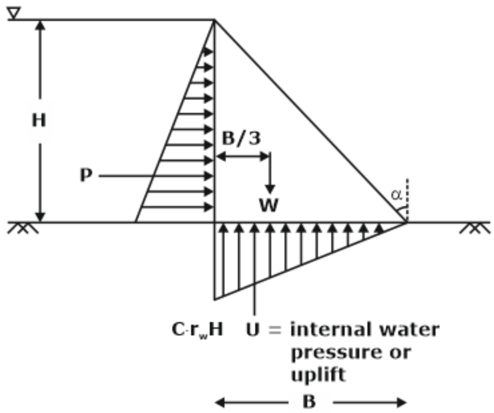


The above diagram shows that for no tension failure, resultant force must always pass through the middle third strip of the base width.



III. ELEMENTARY PROFILE OF GRAVITY DAM

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



Here,

C = U/L uplift pressure coefficient

C = 1, if uplift pressure is considered

C = 0, if uplift pressure is absent

Case 1: When the reservoir is empty

The eccentricity in this profile = $\frac{B}{2}-\frac{B}{3}=\frac{B}{6}$

In this case, there will be

a) No overturning failure

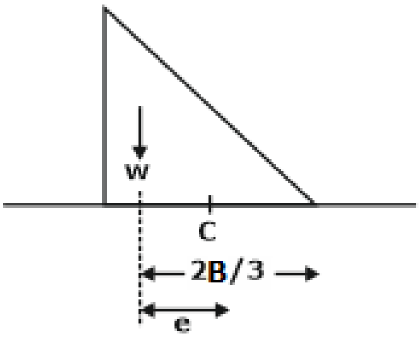
b) No sliding failure

c) No tension failure

The only mode of failure in an empty reservoir case is crushing.

For no crushing mode of failure,

$$(\sigma_{V_{max}})_{toe} = \frac{\Sigma V}{B}\left(1 + \frac{6e}{B}\right)$$
$$= \frac{W}{B}(1 + 1) = \frac{2W}{B} \leq f$$



Case 2: When Reservoir is full

(a) For no tension failure:

For no tension failure:

$$e \leq B/6$$
$$\Rightarrow B \geq \frac{H}{\sqrt{S_c - C}}$$
$$\therefore B_{min} = \frac{H}{\sqrt{S_c - C}}$$

The critical width will be corresponding to the case when uplift pressure intensity is zero.

$$B_{Critical} = \frac{H}{\sqrt{S_c}}$$

Where,

S_c = specific gravity of concrete

C = uplift pressure intensity factor

H = height of the dam.

(b) For no overturning failure:

$$\because M_r \geq M_o$$

$$\Rightarrow B \geq \frac{H}{\sqrt{2(S_c - C)}}$$

$$\therefore B_{min} = \frac{H}{\sqrt{2(S_c - C)}}$$

And,

$$B_{Critical} = \frac{H}{\sqrt{2\,S_c}}$$

(c) For no sliding failure:

For no sliding failure,

Resultant force ≥ shear force

$$\Rightarrow B \geq \frac{H}{\mu(S_c - C)}$$

$$\therefore B_{min} = \frac{H}{\mu(S_c - C)}$$

When there is no upward force,

$$B_{Critical} = \frac{H}{\mu\,S_c}$$

(d) For no crushing failure:

For no crushing failure

$$\Rightarrow H \leq \frac{f}{\gamma_w\,(S_c - C + 1)}$$

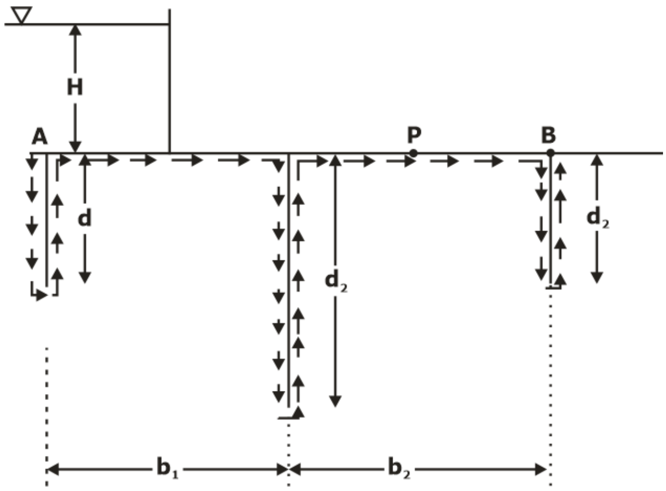
$$\Rightarrow H = \frac{f}{\gamma_w\,(S_c - C + 1)_{max}}$$

And, critical height for the dam is

$$\Rightarrow H_{Critical} = \frac{f}{\gamma_w\,(S_c + 1)}$$

CHAPTER 6: SEEPAGE THEORY

I. BLIGH'S CREEP THEORY FOR SEEPAGE FLOW



- According to Bligh's theory, the percolating water flows the outline of the base of the foundation of the hydraulic structure.
- The length of the path thus traversed by water is called the length of the creep.
- It is assumed that the loss of the head is proportional to the length of the creep.
- If H_2 is the total head loss between the upstream and downstream and L is the creep length, then the head per unit of creep length is called the hydraulic gradient.
- Now, for any point P, an impervious floor

L = total length of creep.

$$L = 2d_1 + b_1 + 2d_2 + b_2 + 2d_3$$

Let the length of creep = L_p

$$\text{Head loss till } P = H_{2_p} = \frac{H}{L} \times L_p .$$

$$\text{Residual seepage head @ } P = H_R = H - \left(\frac{H}{L}\right) \times L_p = h$$

a. Safety against piping or undermining

According to Bligh's theory, safety against piping or undermining following conditions should be satisfied.

$$\frac{H}{L} \le \frac{1}{C}$$

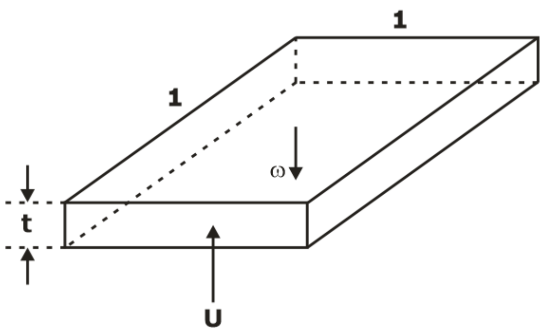
$$\Rightarrow \; L \ge CH$$

Here, C = Bligh's creep co-efficient.

Type of soils	Value of C
Fine micaceous sand	15
Coarse-grained sand	12
Sand mixed with boulder and gravel	5 to 9
Light sound and mud	8

b. Safety against uplift pressure

At any point P →



$$t_{min} = \frac{h}{G-1} \text{ and } t_{design} = \frac{4}{3}\left(\frac{h}{G-1}\right)$$

Here, γ_ω= unit weight of water.

G = specific gravity of the floor material.

By the above expression, the thickness of the floor can be determined. This is generally increased by 33% to allow a suitable factor of safety.

II. LANE'S WEIGHTED CREEP THEORY

- According to Lane's weighted creep theory, the weighted creep length is given as per the following expression.

$$\boxed{L_\omega = \frac{N}{3} + V}$$

Where N = sum of horizontal creep length as per Bligh

V = sum of vertical creep length as per Bligh.

a. Safety against piping failure

The following condition is to be satisfied to avoid piping failure.

$$\frac{L}{L_\omega} \le \frac{1}{C_1}$$

$$\Rightarrow \quad L_\omega \ge C_1 H$$

Here, C_1 = weighted creep coefficient for any soil.

Types of soil	Value of G
Very fine sand or silt	8.5
Fine sand	7.5
Coarse sand	5.0
Gravel and sand	3.5 to 3.0
Boulder, gravels and sand	2.5 to 3.0
Clayey soils	3.0 to 1.6

b. Safety against the uplift pressure

$$t_{min} = \frac{h_\omega}{G-1} \text{ and } t_{design} = \frac{4}{3} \cdot \frac{h_\omega}{G-1}$$

Where $h_\omega = H - \frac{H}{L_\omega} \times L_{\omega_p}$

III. KHOSLA'S THEORY

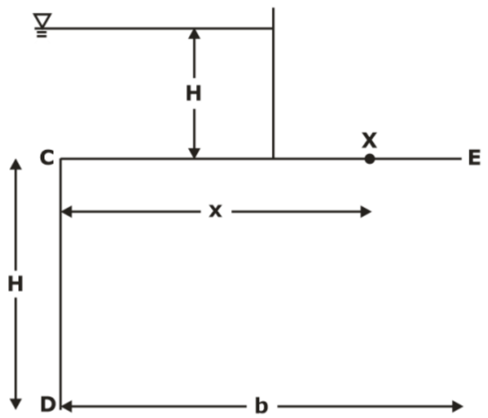
- Residual seepage head, as per Khosla's theory, is given by following potential functions

$$P = \frac{H}{\pi} \cos^{-1}\left(\frac{2x}{b}\right)$$

Here,

φ = residual seepage head potential function, given as, $\phi = \frac{1}{\pi} \cos^{-1}\left(\frac{2x}{b}\right)$

H = total seepage head,



Critical Hydraulic Gradient

- As per the observations of Khosla's theory, the exit gradient at the downstream end of the floor is given by the following expression.

$$G_E = \frac{H}{d} \times \frac{1}{\pi\sqrt{\lambda}}$$

There, H = total seepage head

d = depth of pile at the downstream end of the impervious floor.

$$\lambda = \frac{1 + \sqrt{1 + \alpha^2}}{2}$$

$$\text{Where, } \alpha = \frac{b}{d}$$

b = total horizontal length of the floor.

Critical hydraulic gradient $CHG|_{\text{For soil}} = (1 - \eta)(G - 1)$

Here η = porosity

G = Specific gravity.

For no piping failure,

$$\boxed{G_E \le CH \cdot G}$$

CHAPTER 7: CROSS DRAINAGE

I. RIVER TRAINING & PROTECTION WORKS

- River training implies certain measures adopted on a river to stabilize the river channel along a certain alignment with a certain cross-section.

II. MORPHOLOGY OF A RIVER

- River/Stream morphology describes the shape of river channels and how they change in shape with direction with respect to time.

III. THALWEG OF A RIVER

- A thalweg or talweg is the line of lowest elevation within a Valley or watercourse.

IV. GROYNES/SPURS

- Groynes are constructed transverse to the river flow.
- It extends from the bank into the river up to a limit.

  Types of Groynes: Groynesare classified based on function

  a. Repelling/Reflecting Spur,

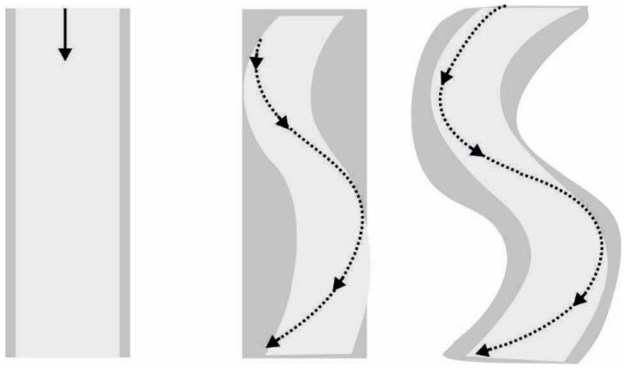
  b. Deflecting Spur,

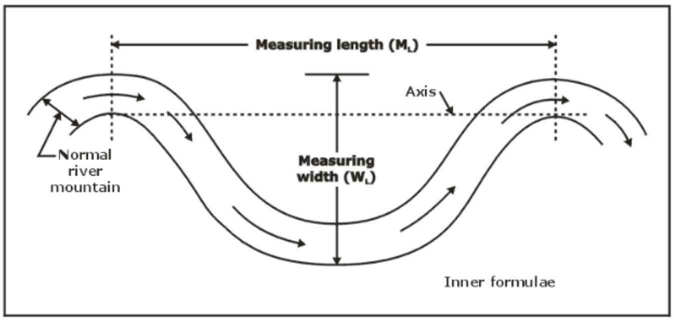
  c. Attracting Spur

  d. T-Shaped (Denehey), Hockey (Or Burma) Type, Kinked Type, Etc.

V. MEANDERING OF RIVERS

- A meandering type of river flows in consecutive curves of reverse order connected with a short strait called a crossing.





$$M_B = 153.42 \sqrt{Q}$$

$$M_L = 53.61\sqrt{Q}$$

$$M = 8.84 \sqrt{Q}$$

Where Q is in m^3/s;

M_B, M_L, W in meter.

a. Sinuosity or Tortuosity

- It is the ratio of the Actual length (along the curve) to the Meander Length (along a straight line) between the curve's endpoints of a meandering river.

b. Effect of Meandering

- The meandering action increases the length of the stream or river and tends to reduce the slope.

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