1 Irrigation and its Methods

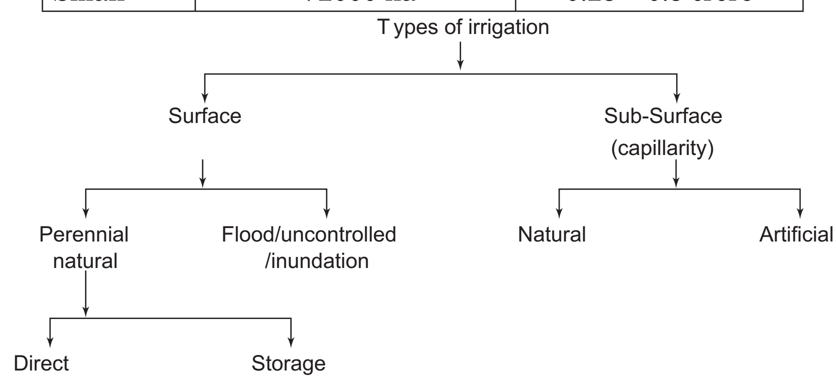
Irrigation is the science of artificial application of water to the land, in accordance with the crop requirements throughout the crop period for full-fledged nourishment of the crops.

Crop yield expressed in quintal/ha or tonnes/ha.

Productivity is expressed as crop yield per mm of water applied.

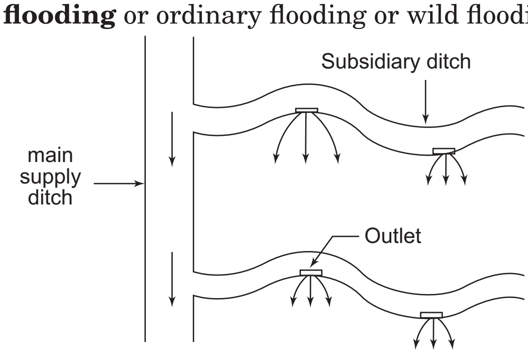
Types of irrigation projects

Projects	Irrigation Potential CCA	Cost of project
Major	> 10,000 ha	> 5 crore
Medium	2000 – 10,000 ha	0.5 – 5 crore
Small	< 2000 ha	0.25 – 0.5 crore



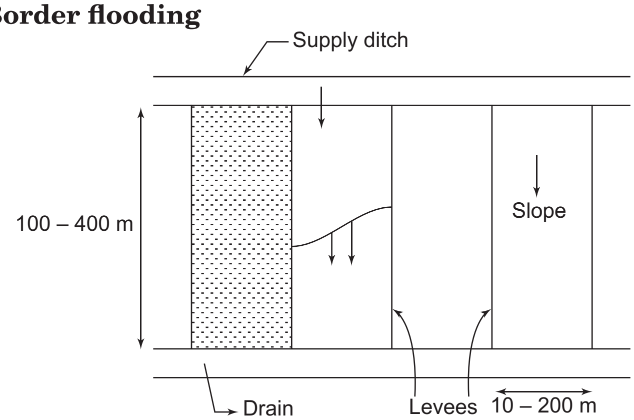
Methods of irrigation

(1) Free flooding or ordinary flooding or wild flooding



• used for rolling land where borders, checks, basins and furrows are not feasible.

(2) Border flooding



$$t = 2.303\ \frac{y}{f}\ \log \frac{Q}{Q - fA}$$

Q = Discharge through supply ditch

A = Area of land strip to be irrigated

y = depth of water flowing over the border Strip.

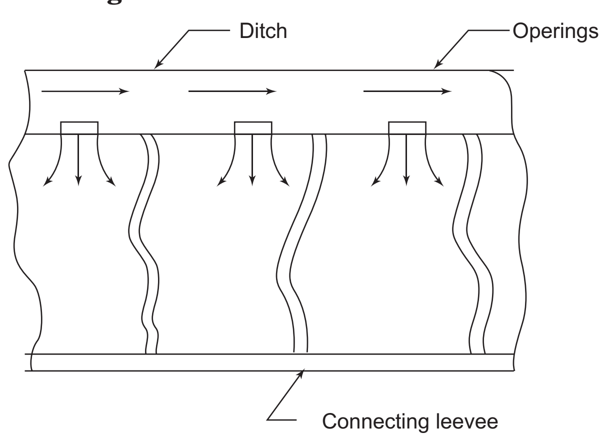
f = Rate of infiltration of soil.

t = Time required to cover the given Area A

$$A_{max} = \frac{Q}{f}$$

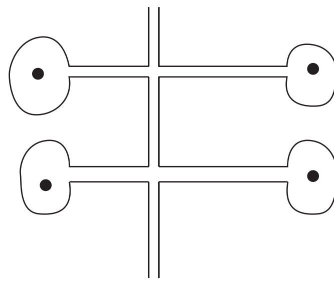
Note : Surface flow will stop after A_{max} and deep percolation will start.

(3) Check flooding



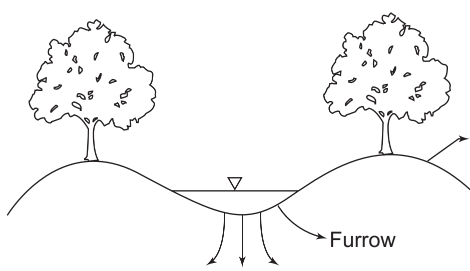
- Close growing crops like jowar & paddy.
- Deep homogeneous loam or clay soil with medium infiltration rate.
- Suitable for both permeable and less permeable soil.

(4) Basin flooding



- Special type of check flooding and adopted specially for orchard trees.
- Basin shape may be irregular, square, rectangular, circular.
- Not suitable for coarse sand.

(5) Furrow irrigation



- Less evaporation
- Less wastage of land
- Wide range of natural slopes
- Preferred in flat or gentle slopes.

(6) Sprinkler irrigation

- Not suitable for soil with low infiltration rates (eg clay).
- Best suited for very light soil.
- Generally used for Tea, Coffee, Not at all used in Rice or Jute.

Note : For rice and jute, standing water is used

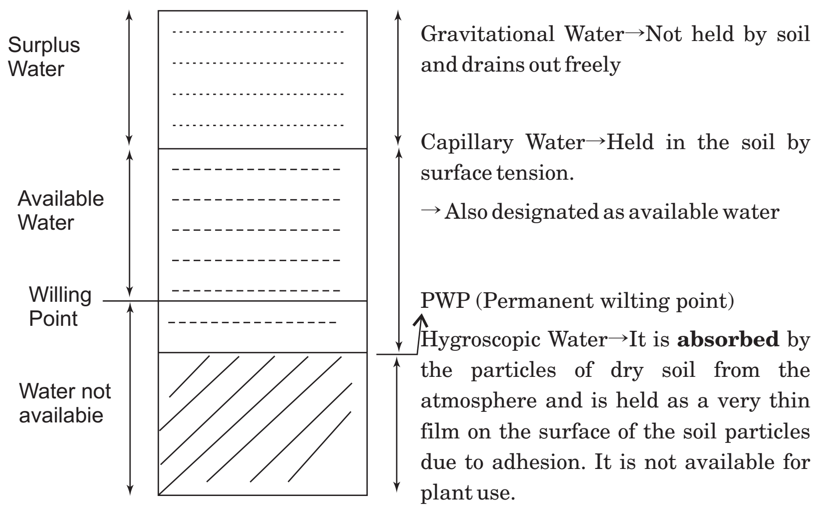
(7) Drip irrigation

- Best suited for row crops and orchards like grapes, tomatoes, cabbage etc.
- Water and fertilizer is slowly and directly applied to the root zone of the plants.
- Achieved with the help of specially designed drippers and emitters.

Note : Sprinkler and drip irrigation systems falls under a category known as pressurised irrigation systems.

2 Soil-moisture Plant Relationship

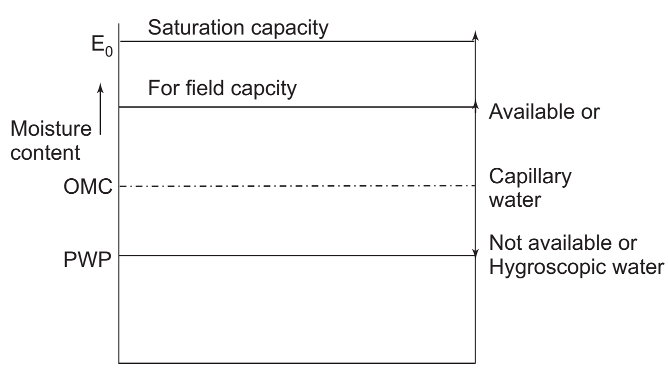
Classification of Soil water



Soil moisture tension: Tenacity with which water is retained in the soil, measured as force per unit area. Generally expressed in atmosphere.

Soil moisture Stress = Soil moisture tension + Osmotic Pressure

The Osmotic pressure of the soil solution must be maintained as low as possible by controlled leaching.



Saturation capacity→ Max water holding capacity of the soil.

Field capacity→ Max amount of moisture which can be held against gravity.

Soil moisture tension at permanent willing point ranges from 7 to 32 atmospheres.

Depth of water stored in the root zone (d_w)

$$\text{Field capacity} = \frac{\text{wt. of water retained in certain volume of soil}}{\text{wt. of same volume of dry soil}} \times 100$$

$$\boxed{d_w = \frac{\gamma_d}{\gamma_w} \times d \times F}$$

F = Field capacity
d = depth of root zone
γ_d = dry unit wt. of soil
γ_w = unit wt. of water
Note:- γ_d is the unit weight of dried soil sample, not of soil solids.

Available moisture depth to plant, $d'_w = \frac{\gamma_d}{\gamma_w} \times d$ (F.C-PWP)

Readily available moisture depth to plant, $d''_w = \frac{\gamma_d}{\gamma_w} \times d$ (F.C-Readily available moisture)

$$\boxed{\text{Porosity} = \text{Field capacity} \times \frac{\gamma_d}{\gamma_w}}$$

Irrigation Water Quality:

(1) Total concentration of soluble salts

$$\boxed{\text{Salinity concentration } (C_s) = \frac{\text{Conc. of salt} \times \text{Qty. of water applied}}{\text{Qty. of water applied + Amount of Rainwall-Qty. of water used}}}$$

- Generally expressed in ppm or mg/l.
- Indirectly measured by determination of electrical conductivity expressed in micro mho's per centimetre

Electrical Conductivity	Class	Uses
<250	Low	For all crops
250-750	Medium	Used after leaching
750-2250	High	High salt tolerant plants
>2250	Very high	Not suitable

(2) Proportion of Sodium ions to other Cations

$$\text{Sodium Adsorption Ratio, SAR} = \frac{Na^{+}}{\sqrt{\dfrac{Ca^{++} + Mg^{++}}{2}}}$$

SAR	Type of water	Uses
0-10	Low sodium water (S_1)	For all crops
10-18	Medium sodium water (S_2)	Only in coarsed grained soil
18-26	High sodium water (S_3)	Used only after leaching
>26	Very high sodium water (S_4)	Not suitable

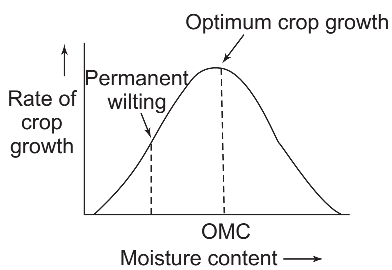
Note : High conc. of bi-carbonate ions may result in precipitation of calcium and magnesium bicarbonates, which will relatively increase the sodium concentration, and will become hazardous.

3 Water Requirement of Crops

Type of crop

Rabi (winter crop)
- Oct-March
- Potato, wheat, pulse gram, mustard, barley etc.

Kharif (monsoon crop)
- April-September
- Jowar, soyabean, Rice Bajra, Cotton, Maize etc.



Crop period: Time b/w sowing of crop and its harvesting.

Base period: Time b/w first watering and last watering done before harvesting.

$$\text{Crop period} > \text{Base period}$$

Duty: Area of land in hectares that can be irrigated when one cumec of water is supplied throughout entire base period. Expressed in hectare per cumec.

Delta: Total depth of water applied over an irrigated land at different watering throughout entire base period. Denoted by and expressed in cm or m.

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

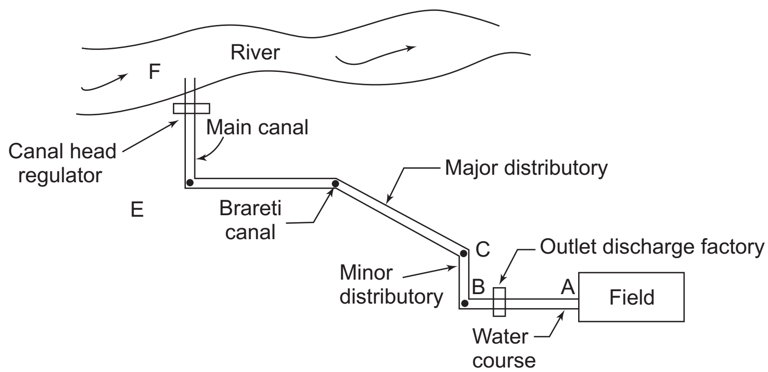
$\Delta \rightarrow$ meters

$B \rightarrow$ Base period in days

$D \rightarrow$ hec/m^3

$$\text{Duty}_A > \text{Duty}_B > D_C > D_D ... > D_F$$

If duty at A = D
And there are 20% losses
then,
Duty at F = 0.8D



Commanded area: Area to be irrigated by canal system.

Gross command area (GCA): Total area that can be irrigated if unlimited supply of water is available.

Culturable command area (CCA): That part of GCA which is fit for cultivation.

Intensity of irrigation: Percentage of CCA that is proposed to be cultivated annually.

Note: Intensity can be even greater than 100%. For Eg. If intensity of Rabi crop is 70% and that of Kharif crop is 50% then, Total intensity is 70+50 = 120%

Crop-Ratio: Ratio of area's of land irrigated in Rabi and Kharif season. It is to be selected such that discharge through canal remains uniform.

Paleo Irrigation: Watering done prior to sowing of crop.

Kor Watering (Kor depth or Kor period): First watering after the plants have grown few centimetres (similarly for other's)

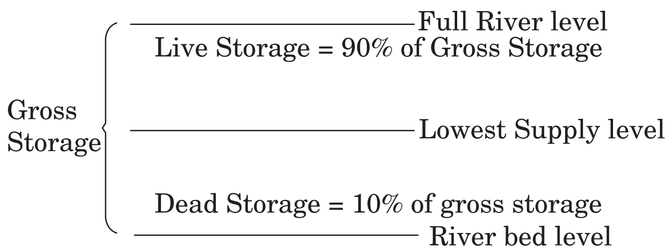
Outlet Factor: Duty of water at the head of field channel, also called outlet discharge factor.

Capacity Factor: Ratio of mean supply discharge of canal to maximum discharge capacity

Duty on capacity: Duty at the head of canal.

Time Factor: No. of days canal actually run to the total number of days of the watering period.

Cash crops: Crops that cannot be consumed directly by the cultivators. Crops like Jute, Tea, Cotton, Sugarcane, tobacco are excluded from the list of cash crops.



Irrigation Efficiencies

1. Water Conveyance Efficiency (η_c)

$$\boxed{\eta_c = \frac{W_f}{W_r} \times 100}$$

W_f = water delivered to field

W_r = water diverted from River to canal

It accounts for losses in conveyance system.

2. Water Application Efficiency (η_a)

$$\boxed{\eta_a = \frac{W_s}{W_f} \times 100}$$

W_s = water stored in the root zone

W_f = water delivered to field

It accounts for loss due to surface runoff and deep-percolation.

3. Water Use Efficiency (η_u)

$$\boxed{\eta_u = \frac{W_u}{W_f} \times 100}$$

W_u = water used beneficially including leaching

4. Water Storage Efficiency (η_s)

$$\boxed{\eta_s = \frac{W_s}{W_a} \times 100}$$

W_s = water stored in the root zone during irrigation

Where, W_n = Field capacity – Available moisture

5. Water distribution Efficiency (η_d)

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

y = average numerical deviation in water depth.

d = average depth of water stored in root zone.

6. Consumptive use Efficiency (η_{cu})

$$\eta_{cu} = \frac{W_{cu}}{W_d} \times 100$$

W_{cu} = consumptive use of water
W_d = net amount of water depleted from root zone

Irrigation requirements of crops

1. Consumptive Irrigation requirement (CIR)

$$CIR = E_t - R_e$$

E_1 = Evapotranspiration
R_e = Effective Rainwall

2. Net Irrigation requirement (NIR)

$$NIR = CIR + LR + PSR + NEW$$

LR = Leaching requirement
PSR = Pre Sowing requirement
NSR = Nursery water requirement

3. Field Irrigation Requirement (FIR)

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

η_a = Application Efficiency

4. Gross Irrigation Requirement (GIR)

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

η_a = conveyance efficiency

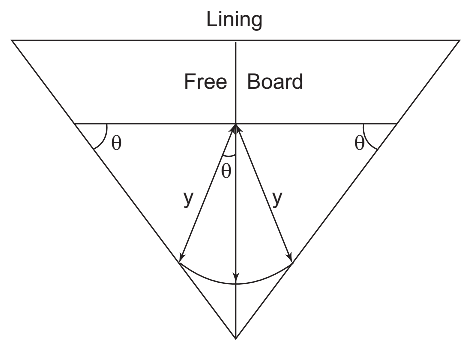
Note: $GIR > FIR > NIR > CIR$

4 Canal-Design

Design of lined canals

(1) Triangular section (For Q < 150m^3/sec)

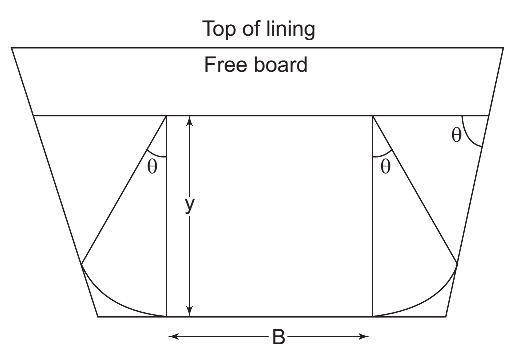
$$A = y^2 (\theta + \cot\theta)$$
$$P = 2y (\theta + \cot\theta)$$



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

(2) Triangular section (For Q>150m^3/sec)

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



Economic justification of lining of canal:

Benefit cost ratio ≥ 1

$$\text{Average Annual Benefits} = mR_1 + PR_2$$

$m \rightarrow$ cumec of water saved due to lining

$R_1 \rightarrow$ irrigation water sold to farmer's at ₹ R_1/cumec

$P \rightarrow$ % of saving achieved in maintenance cost by lining

$R_2 \rightarrow$ Rate of maintenance cost in Rupees per year

$$\text{Annual cost of lining} = \frac{c}{y} + \frac{c}{2}\frac{r}{100}$$

c = Total initial investment

y = service life in years

r = rate of annual simple interest

$$\frac{\text{Benefit}}{\text{cost}} = \frac{mR_1 + PR_2}{\frac{c}{y} + \frac{c}{2}\left(\frac{r}{100}\right)} \geq 1$$

Design of unlined canal

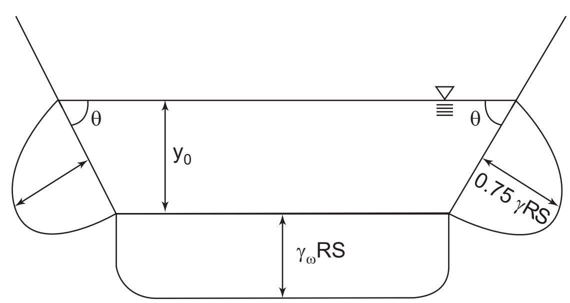
$$\tau_0 = \gamma RS$$

Where, τ_0 = Tractive force at the bottom of the channel

$$\frac{\tau'_0}{\tau_0} = 0.75$$

τ'_0 = Average tractive force at the channel side

$$\tau_c = 0.056\gamma_\omega d\,(G_s - 1)$$



τ_c = critical tractive stress at channel bottom

G_s = specific gravity of sediment ≈ 2.667

$$\tau'_c = \tau_c\sqrt{1 - \frac{\sin^2\theta}{\sin^2\phi}}$$

θ = side slope angle

φ = angle of repose of soil

Note: For no sediment movement from

(*a*) Channel bottom $\tau_0 \le \tau_c$ i.e $d \ge 11$ RS

(*b*) Channel sides $\tau'_0 \le \tau'_c$

Kennedy's theory

(1) $V_0 = 0.55\, m\, y^{0.64}$ where

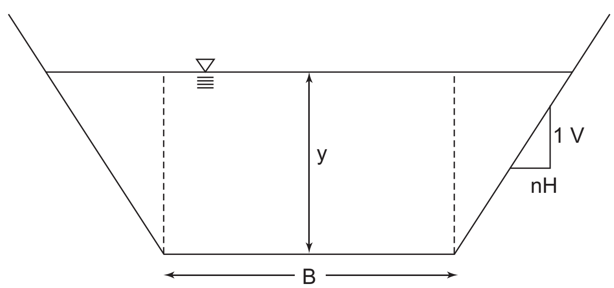
Critical velocity ratio, $m = \dfrac{V}{V_0} = \dfrac{\text{Actual mean velocity}}{\text{critical velocity}}$

m = 1, standard particles

m = 1 to 1.2, coarser sediments

m = 0.7 to 1, finer particles

(2)



$$A = (B + ny)\,y \qquad ...(1)$$

$$A = \frac{Q}{V_0} \qquad ...(2)$$

Get B from (1) and (2)

(3) $P = B + 2y\sqrt{n^2 + 1}$

(4) $R = \dfrac{A}{P}$ R = Hydraulic mean depth

(5) $V = C\sqrt{RS}$ where $C = \dfrac{\dfrac{1}{n} + \left(23 + \dfrac{0.00155}{S}\right)}{\dfrac{1}{n} + \left(23 + \dfrac{0.00155}{S}\right)\dfrac{n}{\sqrt{R}}}$

or

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

(6) If $V \approx V_0$ then ok, otherwise repeat.

Lacey's theory:

He gave three regime concept (*a*) True (*b*) Initial (*c*) Final

- Equations given by lacey are based on final regime concept.
- Total no of independent equations of Lacey's regime theory are **3**.

(1) $v = \left(\dfrac{Qf^2}{140}\right)^{1/6}$ where, silt factor $f = 1.76\sqrt{d_{mm}}$

(2) $R = \dfrac{5}{2}\dfrac{V^2}{f}$

(3) $A = \dfrac{Q}{V}$

(4) $P = 4.75\sqrt{Q}$

(5) $S = \dfrac{f^{5/3}}{3340Q^{1/6}}$

(6) Lacey's regime scour depth $= 1.35\left(\dfrac{q^2}{f}\right)^{1/3}$

5 Earthen-Dams

Built with natural material with very less processing and use of primitive equipments.

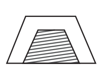
Causes of Failure

- Hydraulic Failure
  - Overtopping
  - Erosion of u/s Face
  - Gully formation in d/s Face
  - Erosion of d/s toe
  - Cracks due to frost action
- Seepage Failure
  - Piping through Foundation
  - Piping through dam body
  - Sloughing → Progressive removal of soil from wet d/s face
- Structural Failure
  - Sliding of Slopes
  - Liquefaction
  - Burrowing Animals
  - Water soluble material
  - Earthquake

Measures to control seepage through earth dam

Reduce quantity of water of Seepage

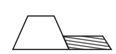
- In Dams (Provide Impervious core of clay)
  - Central Vertical Core

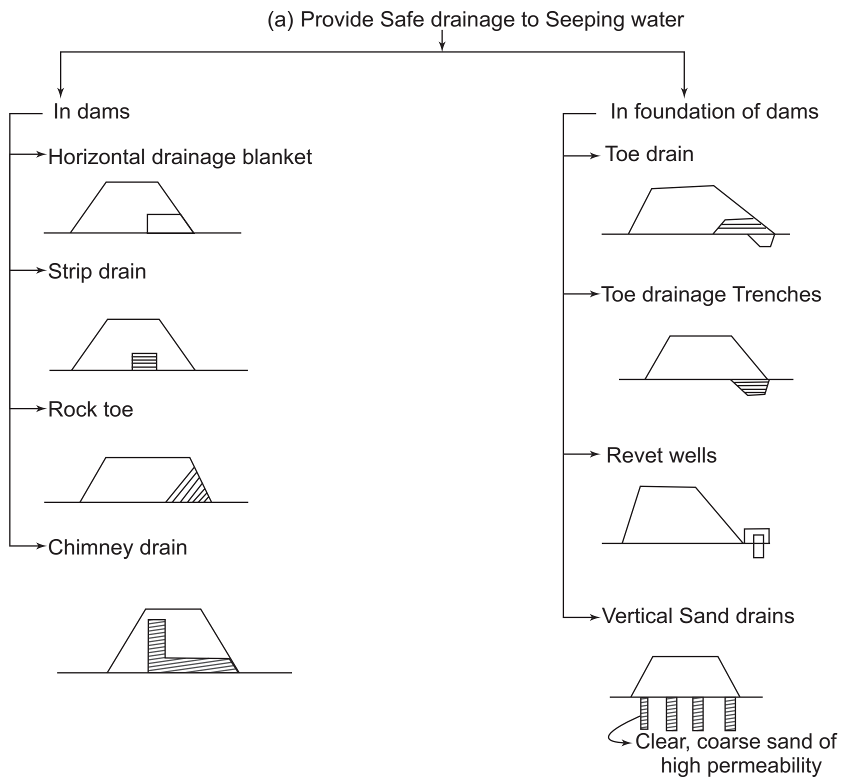


  - u/s Inclined Core

- In Foundation of dams
  - Cut off
    - Full cut off
    - Partial cut off
  - u/s Impervious Blanket

  - D/S Berm




(a) Provide Safe drainage to Seeping water
In dams
Horizontal drainage blanket
Strip drain
Rock toe
Chimney drain
In foundation of dams
Toe drain
Toe drainage Trenches
Revet wells
Vertical Sand drains
Clear, coarse sand of
high permeability

Canal-Irrigation

6

An artificial channel constructed to carry water from aa river, tank or reservoir for various purpose.

Classification based on

- Purpose
  - Irrigation canal
  - Power canal
  - Navigation canal
- Nature of source of supply
  - permanent
    - perennial
    - non-perennial
  - Inundation
- Function
  - Feeder → water for another canal only
  - Carrier → both direct irrigation and feeding another canal also
- Discharge
  - Main canal
  - Branch
  - Major distributary
  - Minor distributary
  - Field channel
- Financial output
  - Productive
  - Protective
- Soil over which its constructed
  - Alluvial canal
  - Non Alluvial canal (NAC)
- Lining
  - Lined canal
  - unlined canal

Note: Indra Gandhi Canal is a feeder canal

On the Basis of **Canal Alignment**, it can also be classified as

(1) **Ridge or Watershed**
→ Aligned alongridge
→ Irrigate areas on both sides
→ No drainage intersects
→ Cross-drainage works not required

(2) **Contour Canal**
→ Aligned parallel to controur
→ Irrigate only on one side
→ Cross drainage works are required
→ Generally in hilly areas

(3) **Side - Slope Canal**
→ Aligned at right angles in the contours
→ Parallel to natural drainage
→ Cross drainage works not required

Water-Logging

7

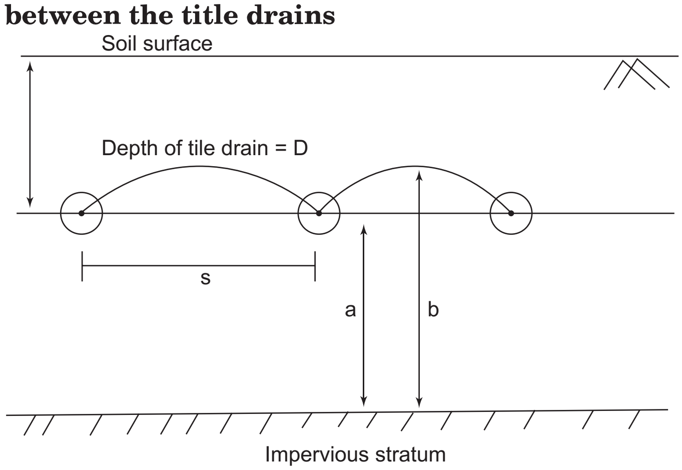
War bandhi: System of equitable water distribution by turns, according to predetermined schedule.

Mulching: Spreading of extraneous material ont he surface of soil to increase water filteration.

Reclamation: Process by which an uncultivable land is made fit for cultivation.

Leaching: Process in which land is flooded with water. So that alkali salts get dissolve in water and percolate to join the water table.

Spacing between the title drains



$$S = \frac{4k}{q}(b^2 - a^2)$$

k = Permeability coefficient (m/sec)

q = discharge per unit length

b = height of water table above impervious layer

a = height of centre of drain above impervious layer

Note: For Reclamation of Alkaline soil, Gympsum as well as leaching is done while for Acidic soil, limestone is used.

Leaching requirement (L.R.)

$$\text{L.R.} = \frac{\text{Depth of water drained out per unit area}}{\text{Depth of water applied per unit area}} = \frac{D_d}{D_a}$$

$$\text{L.R.} = \frac{\text{Salt content of irrigation water}}{\text{Salt content of drained water}} = \frac{C_i}{C_d}$$

$$\text{L.R.} = \frac{\text{Electrical conductivity of irrigation water}}{\text{Electrical conductivity of drained water}} = \frac{E.C_i}{E.C_d}$$

Gravity Dams

8

A dam is a barrier constructed across river in order to create a reservoir for impounding water.

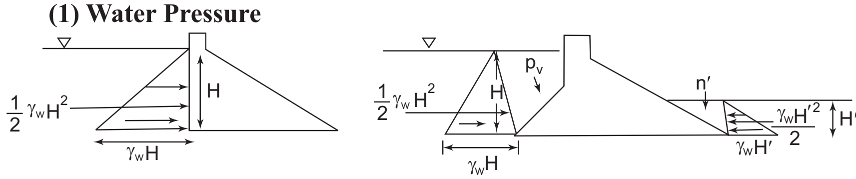
Classification (Based on)

- Function Behaviour
  - Storage dam or impounding dam
  - Detention dam
  - Diversion dam
  - Coffer dam
  - Debris dam
- Hydraulic design
  - Overflow dam
  - Non-overflow dam
- material of construction
  - Rigid dam
  - Non-Rigid dam
- Structural Behaviour
  - Gravity dam
  - Arch dam
  - Buttress dam
  - Embankment dam

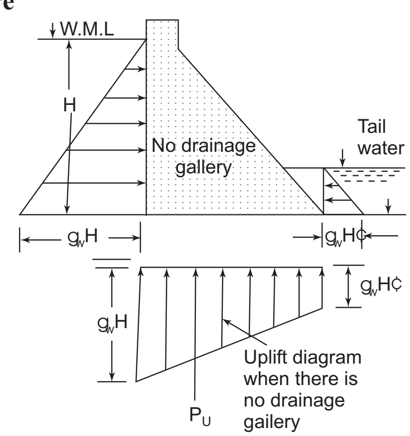
Gravity dam: It is a solid masonry or concrete structure with an approximate triangular cross-section, so that external forces exerted on it are resisted by its own weight.

Forces acting on gravity dam

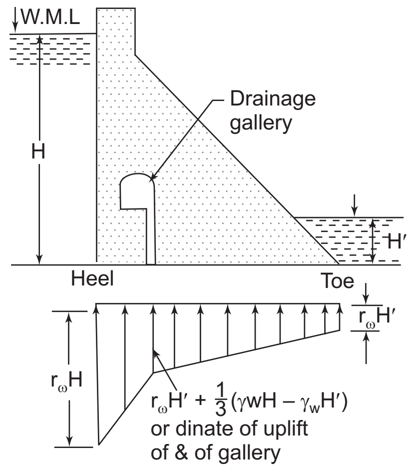
(1) Water Pressure



(2) Uplift Pressure



(a) When there is no drainage gallery



(b) when drainage gallery is present

(3) Earthquake Forces: India is divided into 4 seismic zones, zone I, zone III, zone IV & zone V.

Zone V is most serious zone.

(*i*) Effect due to vertical acceleration (α_v)

Net effective wt. of the dam reduces to $= W = \dfrac{W}{g}\alpha_v$

$= W(1 - K_v)$ where $\alpha_v = Kvg$

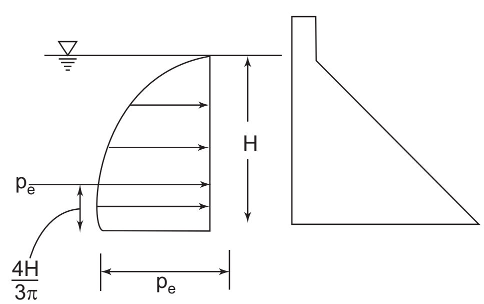
Vertical acceleration acting downward reduces weight of the dam.

(*ii*) Effect due to horizontal acceleration (α_h)

(*a*) Horizontal Inertia force $F_H = \left(\dfrac{W}{g}\right)\alpha_H$

(*b*) Hydrodynamic pressure

$$\boxed{P_e = 0.555K_h\gamma_w H}$$



Acts at a height of $\frac{4H}{3\pi}$ from the base

Moment about base $M_e = P_e\left(\frac{4H}{3\pi}\right)$

$$\boxed{M_e = 0.42 P_e H}$$

(4) **Silt Pressure** $\boxed{P_{\sin} = \frac{1}{2}\gamma_{sub} h^2 K_a}$ $K_a = \frac{1 - \sin\phi}{1 + \sin\phi}$

If the u/s face is inclined, the vertical weight of the silt supported on the slope also acts as vertical force.

(5) Wave Pressure

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

h_w = height of wave (meter)

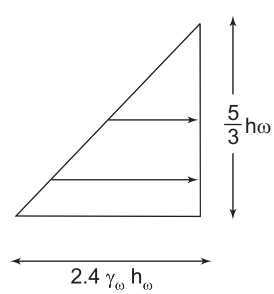
V = Wind Velocity (Km/hr)

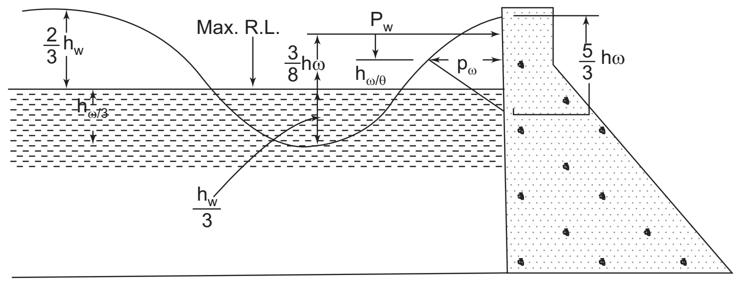
F = Fetch (Km)

$\boxed{\text{Max. } P_w = 2.4\gamma_w h_w}$ acting at height of $\frac{h_w}{8}$ from still water

Total force due to wave action

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





$$\boxed{P_w = 19.62 h_w^2 \text{ KN/m}}$$

P_w at a distance of $\frac{3}{8} h_w$ from reservoir surface.

(6) Ice Pressure: Pressure thrust on the face of the dam due to expanding or melting of ice.

(7) Weight of the dam: $\boxed{W = \gamma_c V}$

γ_c = unit weight of concrete

V = Volume of dam body per unit length.

Criteria of Structural Stability and modes of failure of Gravity dam

(1) Overturning about Toe

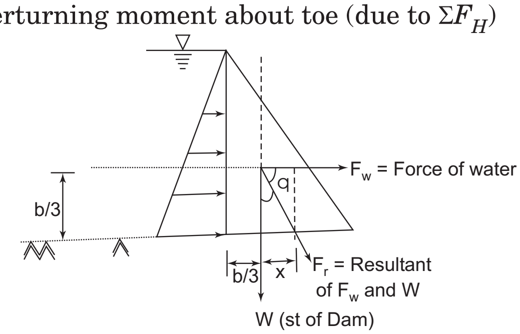
$$F_R = \sqrt{F_H^2 + F_y^2}$$

$$e = \frac{B}{2} - \bar{x}, \bar{x} = \text{distance of } \overline{F_R} \text{ from toe}$$

$$\boxed{F_S = \frac{M_R}{M_O} > 1.5}$$

M_R = Restoring moment about toe (due to ΣF_V)

M_O = Overturning moment about toe (due to ΣF_H)



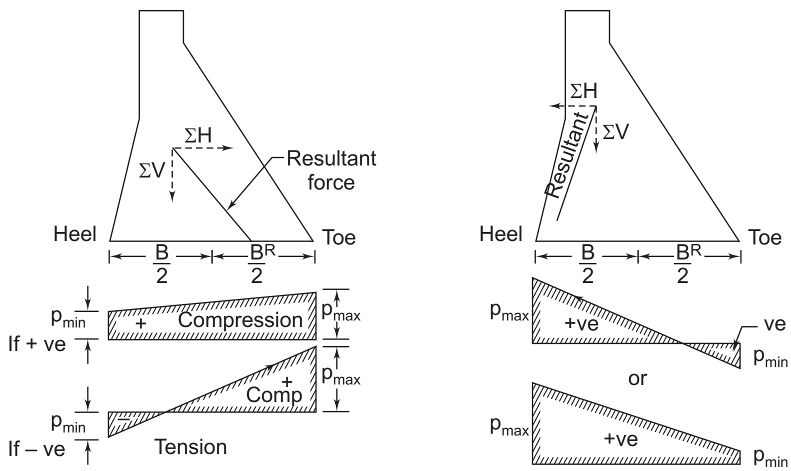
(2) Compression or crushing failure

$$\sigma_{max/\,min} = \frac{\Sigma V}{B}\left(1 \pm \frac{6e}{B}\right)$$

Σ_V = Total vertical force

B = Base width

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



(3) Tension failure: max. permissible tensile stress for high concrete gravity dams under loading conditions may be taken as 500 KN/m^2. For No tension at the base of the dam, $\sigma_{min} = 0$

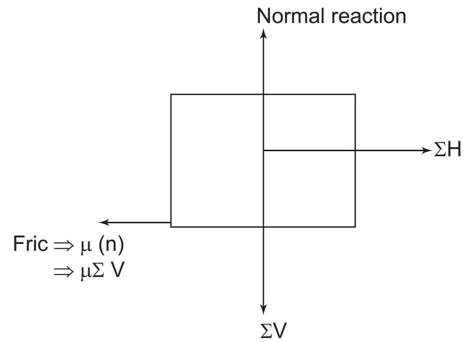
$$1 - \frac{6e}{B} = 0 \Rightarrow \boxed{e = \frac{B}{6}}$$

Middle third rule: For No tension at base, max. permissible value of eccentricity on either side is B/6.

(4) Failure due to sliding

$$\text{FOS}_{\text{sliding}} = \frac{\mu \Sigma F v}{\Sigma H}$$

$$\frac{\Sigma H}{\Sigma V} = \text{sliding factor}$$



$$FOS = \frac{\mu}{\text{sliding factor}} > 1$$

Note: If Shear resistance of joint is also considered, then equ. of FOS against sliding is measured by shear friction factor (SFF)

$$\text{S.F.F} = \frac{\mu \Sigma v + Bq}{\Sigma H}$$

B = width of dam (metre)

q = Permissible Shear (KN/m^2)

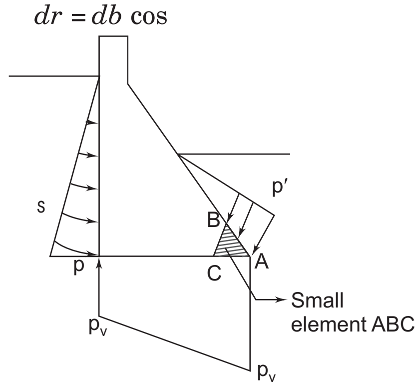
Principal and Shear Stresses

(1) **Principal Stress** put $\Sigma v = 0$

$$p' ds \sin \alpha + \sigma\, dr \cos \alpha = p_v\, db$$

where, $ds = db \sin$

$dr = db \cos$



So,

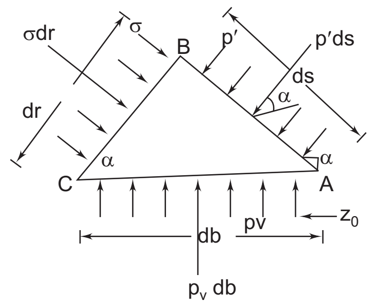
$p' \sin^2\alpha + \sigma\, dr \cos^2 \alpha = p_v$

Resolving

$$\sigma = p_v \sec^2 \alpha - p' \tan^2 \alpha$$

(*a*) For No tail water, $p' = 0$

$$\boxed{\sigma_{max} = p_v \sec^2 \alpha}$$



(*b*) If hydrodynamic pressure p'_e then

$$\boxed{\sigma = p_v \sec^2 \alpha - (p' - p_e) \tan^2 \alpha}$$

(2) **Shear Stress** put $\Sigma H = 0$

$$\boxed{\sigma\, dr \sin \alpha - p' ds \cos \alpha = \tau_0\, db}$$

Substituting and Resolving, $\boxed{\tau_0 = (p_v - p') \tan \alpha}$

(*a*) For No tail water $P^1 = 0$ $\boxed{\tau_0 = p_v \tan \alpha}$

(*b*) If hydrodynamic pressure p_e', then $\boxed{\tau_0 = [p_v - (p' - p_e')] \tan \alpha}$

Elementary Profile of a gravity dam

(1) For No tension at base, when reservoir is full

$$\boxed{B \geq \frac{H}{\sqrt{G - C}}}$$

G = Specific gravity of material of dam

C = uplift coefficient

when uplift is not considered, C = 0 $\boxed{B \geq \frac{H}{\sqrt{G}}}$

(2) For No sliding $\boxed{B \geq \dfrac{H}{\mu(G-C)}}$

Max. stress at toe, $P_V = \gamma_\omega H\,(G - C)$

Min stress at heel $P_V = 0$

Principal Stress near toe $\sigma = \gamma_\omega H\,(G - C + 1)$

Shear Stress near toe $\tau_0 = \gamma_\omega H\sqrt{G - C}$

Note: If max represents the allowable stress of the dam material then maximum height of the dam

$$\boxed{M_{max} = \frac{\sigma_{max}}{\gamma_\omega (G+1)}}$$

If Height of dam is less than H_{max}, then its **low gravity dam**. And if Height is greater than H_{max} then its **High gravity dam**.